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Forest Harvest, Residue Treatment, Reforestation and Protection of Water Quality

James M. Montgomery, Inc.

Prepared For
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April 1976

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FORESTHARVEST, RESIDUE TREATMENT, REFORESTATION & PROTECTION OF WATER QUALITY

PB 253 393

U.S. ENVIRONMENTAL PROTECTION AGENCY

REGION X

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CHAPTER 1
INTRODUCTION

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INTRODUCTION

Purpose

The Federal Water Pollution Control Act Amendments of 1972, PL-92-500, set a national goal of water quality which provides for the protection and propagation of fish, shellfish, and wildlife and which provides for recreation in and on the waters. This goal must be achieved by 1983. The Act mandates that pollution caused by runoff from forest lands, as well as other nonpoint sources (mining, construction, agriculture, etc.), be controlled in addition to the control of point sources in order to achieve the national goal of water quality.

This report is a state-of-the-art reference on the protection of water quality in planning and conducting forest harvest, residue treatment, and regeneration operations based largely on data collected in Region X (Figure 1). It is intended to be an aid for dealing with pollution from nonpoint sources; and is designed to inform and assist state, federal and local agencies; industry; and the general public. The report is specifically intended to assist in the (1) identification of potential hazards to water quality, and (2) selection of procedures, practices, or methods suitable for preventing, minimizing, or correcting water pollution problems. It is also a reference source to other publications, information, and materials.

The Environmental Protection Agency (EPA) has previously prepared reports on "Processes, Procedures and Methods to Control Pollution from Silvicultural Activities," and on "Methods for Identifying and Evaluating the Nature and Extent of Non-Point Sources of Pollutants" both published in October 1973. A third report published in March 1975, by EPA Region X on "Logging Roads and Protection of Water Quality," deals specifically with one important aspect of forest practices. The present report builds on previously published information.

Scope

The report emphasizes summarization of research, currently applied prediction, prevention and control techniques, and criteria for preventing or minimizing water pollution.

Subregions have been defined in Chapter 2 in recognition of the diverse characteristics of the Pacific Northwest. A future goal of water quality management should be to specify the applicability and relevance of the available research information and "best preventative techniques" by subregion. However, there was limited potential for such subregional specificity in this study due to the lack of information concerning the geographic applicability of existing research data and techniques.

Chapter 3 summarizes the current forest practices utilized in Region X. These summaries are brief, but should be sufficient to facilitate a general understanding of the report.

Chapter 4 addresses the impact on water quality of the various forest practices presented in Chapter 3.

In Chapter 5 of the report, various methods and approaches to planning and control are described. Emphasis is placed on providing the reader with summaries concerning: (1) the selection of silvicultural or logging systems based on water quality impact, (2) planning approaches and simulation models, (3) specific operational, design or planning constraints, and (4) the information requirements for monitoring, prediction or planning purposes.

Throughout Region X there are significant potentials for adverse water quality impact from many facets of timber harvest, residue management, and regeneration. The most significant of these potential impacts appears to be related to erosion and sedimentation but in many areas thermal pollution is a significant potential problem. Nutrients held by the soil media and vegetation can result in significant water quality problems but this is generally of less severity than sediment and elevated water temperature.

There are variations in the applicability of the techniques and methods presented in this report. This results from the varying significance from one subregion to another of physical or biological factors such as temperature regime, soils/hydrologic characteristics, geology, fisheries, precipitation pattern and forest types. Users of the report are urged to review the pertinent references to determine the relevance of a specific method or technique in their geographic area of interest.

Significant advances in water quality protection can be made through planning. Depending upon the complexity and degree of water quality impact this may involve interdisciplinary input, use of predictive or impact models, expanded utilization of advanced logging equipment, and guidelines which have been developed for the specific area of consideration.

Throughout the region there is a wide range of physical and biological characteristics. From one operation to another there are widespread differences in the availability of management expertise, field personnel, advanced logging equipment, automated analysis technology and field control. These differences influence the methods by which water quality goals are achieved and suggest a need for various types and levels of planning and management.

Detailed site planning and engineering, complemented by adequate field control, are necessary if the most effective water quality management programs are to be realized. The most efficient solutions involve site specific planning along with broader scope subregional (or areawide) planning and guidelines, impact analysis, and the use of current technology. When these are not available, general management standards are needed to ensure compliance with water quality requirements.

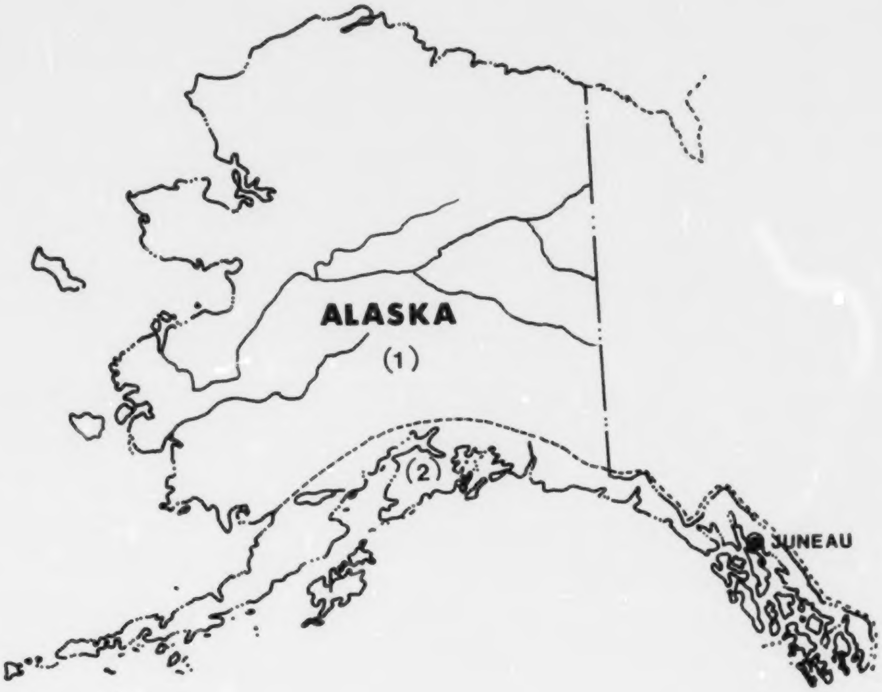
This report does not include a glossary due to the large number and wide range of types of terms involved. The following publications are recommended to report users who are unfamiliar with the terminology herein.

Society of American Foresters, 1971.
Terminology of Forest Science, Technology, Practice and Products; (English language version).

USDA Forest Service, 1969.
Glossary of Cable Logging Terms. PNW Forest and Range Expt. Sta., Portland, Oregon.

USDA Forest Service, 1973.
Silvicultural systems for the major forest, Agriculture Handbook No. 445, 114 p.

Franklin, Jerry F., and C. T. Dyrness, 1973.
Natural Vegetation of Oregon and Washington. USDA Forest Serv. PNW Forest and Range Expt. Sta. Gen. Tech. Rept. PNW-8, 417 p.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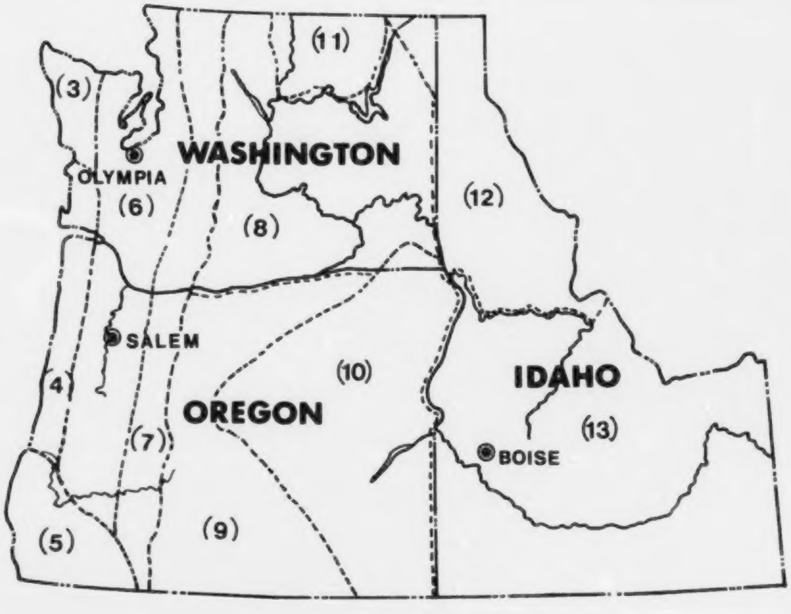
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REGION X
WITH SUBREGIONS

FIGURE 1

CHAPTER 2
BACKGROUND INFORMATION

BACKGROUND INFORMATION

This section includes background information on the fisheries and subregions of Region X. Forest use statistics are not included since this subject is adequately summarized in "Logging Roads And Protection Of Water Quality" EPA, Region X March 1975 which complements this report. The subregional information presented is very brief and intended only as a conceptual framework for understanding, on a comparative basis, the variables which affect water quality and the management techniques selected.

Region X has been subdivided into subregions on the basis of uniformity of forest type, uniformity of usual silvicultural practices and similarities in climate, physiography and hydrology. Influence of a given forest land management practice on water quality varies from one subregion to another based on these factors and the season.

One major difference concerns the runoff pattern. At lower coastal elevations most precipitation occurs as rain, which is immediately available to streams for a hydrologic response and transportation of dissolved and suspended materials. In contrast, precipitation occurring as snow at the higher elevations generally accumulates during the winter and is released as a free water input to streams during the melt season. Thus, the solvent action of water in passing through the forest soil and erosive action in streams and rivers is concentrated in the late spring and early summer.

The discussion of subregions in Region X will identify major forest species, climate, geology, and soil parent material where possible. These data present a framework for discussion of interacting water quality problems with forest management, soils erosion and basic hydrology.

Based on the above rationale, Region X has been divided into the following subregions (see Figure 1):

1) Interior Alaska
2) Coastal Alaska
3) Western Olympics
4) Coastal Washington and Oregon
5) Klamath Mountains
6) Puget-Willamette Trough
7) Western Cascades
8) Eastern Cascades - North
9) Eastern Cascades - South
10) Blue Mountains
11) Okanogan Highlands
12) Northern Idaho
13) Intermountain

In most cases, it was impossible in this study to differentiate between applicable and inapplicable techniques on a subregional basis. However, the subregions defined present a format that can be used for such purposes in future studies.

Interior Alaska

The vast area of Interior Alaska has greatly varied topography, vegative cover and climatic conditions. While large in size, there is little commercial timber harvest in the subregion. Permafrost is found on varying aspects and to varying depths. The occurrence and depth to permafrost greatly influences the vegetative type, vegetative patterns, and annual growth. In general, it is a dry region; however, permafrost holds the moisture near the soil surface resulting in a relatively heavy ground cover of grasses, mosses and shrubs which retard surface runoff.

The better forest stands are confined to lower slopes and valley bottoms of larger rivers and their major tributaries. Forest stands are generally classed commercial in the Interior, if the site is capable of producing 20 cubic feet of wood per acre per year. The most important species is white spruce followed by paper birch, quaking aspen, and balsam poplar. White spruce is generally classed as the climax forest species on most commercial forest lands of the Interior. The best stands of white spruce occur on well-drained soils in river bottoms. Mature stands generally require 100 to 150 years for development. One of the most common trees is the black spruce, which is considered non-commercial.

The climate of Interior Alaska varies from a moderate continental in the southern portion near Cook Inlet, to a subarctic climate in the remainder of Interior Alaska. In the transition between coastal and Interior Alaska (Kenai Peninsula area), mean annual temperatures vary from 32 to 35°F, with the months of June, July and August having average monthly temperatures in excess of 55°F. Precipitation is relatively uniform, showing moderate orographic influences. Over a broad area in the Kenai-Kodiak area, average annual precipitation varies from 30 to 40 inches.

The climate of Fairbanks might be considered as somewhat of an average for interior forested areas. The average annual temperature at Fairbanks is 26°F and can vary locally depending on elevation and aspect from 15 to 36°F. The official all-time low temperature was -66°F in January 1934, with the highest temperature recorded 99°F in July 1919. On the average, the frost free growing season is approximately 90 days. Average annual precipitation is about 10 inches.

The underlying bedrock of Interior Alaska is predominately Tertiary sediments with older Jurassic granitic intrusives. Many of the broad valleys contain very deep alluvial deposits of sand and gravel. Much of the existing topography is a result of reworked material and depositions by glaciers.

As is common in association with glacial activity, many of the soils are windblown loess. These soils occur throughout the interior in depositions of a foot to 10 to 15 feet. In many places, the highly erodible loess soils have been redeposited as alluvial soils in the valleys through normal erosional processes. Soils of the forest stands have generally developed on loess or alluvium, in some cases mixed with ash.

The flow regimes of Interior Alaska streams are typical of a cold snow zone. 40 percent of the annual precipitation usually occurs as snow, which accumulates and is then released in a melt season from May through August with augmentation by rainfall in July and August. Over an extended area of the Interior, the average annual runoff is about 10 inches per year; however, this can be highly variable depending on annual precipitation and summer temperatures. It is not uncommon to have a two- to threefold variation in annual water yield in a very few years.

Coastal Alaska

Coastal Alaska comprises an area of about 33 million acres of which 15.8 million acres are forested (at least 10 percent stocking with trees). The forested zone consists of 5.8 million acres of commercial forest land.

Coastal Alaska is made up of hundreds of islands with a narrow mainland broken by many fjords and inlets. The islands vary in size from those of less than an acre to islands such as Kodiak with 2.3 million acres, and Prince of Wales with 1.6 million acres.

Alaska's coastal forests are similar to the temperate coastal rain forests of Washington and Oregon. The major difference is the absence of Douglas-fir and an increase in Sitka spruce. In the southeast, near Ketchikan, forest stands are composed primarily of western hemlock and Sitka spruce. Interspersed and in occasional small blocks are stands of western redcedar and Alaska cedar. Commercial hardwoods, such as red alder and black cottonwood, are confined to stream bottoms and exposed mineral soil in slide areas. Progressing northwest, western redcedar and Alaska cedar become much less important. Commercially important stands of cottonwood occur in the Haines area, and on most alluvial soils to the west. Sitka spruce becomes an increasingly important species in the northwest coastal regions.

Land forms of southeast Alaska exhibit the complex effects of Pleistocene glaciation with great variety of bedrock types including extensive areas of granitic, metamorphic, volcanic and calcareous rocks. Granitic rock forms are generally more massive and resistant to the erosional powers of glaciers; consequently, they form the most extensive mountain systems. Calcareous (marble and limestone) bedrocks are extensively fractured providing excellent subsurface drainage.

The great pressure of glacial ice overriding previously deposited tills formed extensive areas of compacted till. These compacted tills occur to elevations of about 1,500 feet in many of the U-shaped valleys.

Post glacial, ash and pumice deposits occur over an extensive area on Revilla, Kruzof, Baranof and Chichagof Islands. Ash and pumice mantle many sides and upper valley walls, and have been redeposited on terraces in major river valleys.

The climate of southeast Alaska is wet and cool. Summers are relatively cool, and extreme cold weather is uncommon except at higher elevations. Average annual precipitation near tidewater is about 100 to 150 inches. With relatively small increases in elevation, precipitation ranges to 200 to 300 inches. Rainfall rates are moderate (0.3 to 0.5 inches per hour), and often of long duration. The frost free growing season varies from about 100 days in northern areas, removed from the water, to about 200 days at tide water in the southeastern areas.

Coastal Alaska falls within the hydrologic regime of the warm snow zone. Large amounts of precipitation (20 inches) occur during October and November, and frequent warm rainstorms occur even after snow accumulation begins in December. The combination of steep slopes and abundant precipitation with shallow soils, produces streams with highly variable flow characteristics. Surface runoff varies from 60 to 100 inches for lower elevation watersheds, to 100 to 150 inches and more for intermediate and higher elevations.

Western Olympics

The coastal zone of the Olympic Peninsula combines forest types of the narrow shoreline Sitka spruce type with the western hemlock type. Soils and land forms of the Western Olympics, like Coastal Alaska, are dominated by Pleistocene glaciation.

Near the ocean, Sitka spruce is the dominant species extending up river valleys on recent alluvial soils, frequently for many miles. The western hemlock zone is confined to elevations below 3,000 feet. The species composition consists of western hemlock, Sitka spruce, western redcedar, and Douglas-fir. At higher elevations, removed from the coast, Pacific silver fir becomes an important species. Red alder and cottonwood occur in commercial stands on recent alluvial soils along major rivers.

The climate of the Western Olympics is definitely maritime due to air masses moving inland from the Pacific Ocean. Maximum rainfall occurs in December and January (15 to 20 inches), with minimum amounts in July and August (2 to 4 inches). Precipitation averages 70 to 90 inches at low elevations, increasing with elevation and distance inland to 150 to 170 inches at 1,000 feet, and in excess of 200 inches at higher elevations. Rainfall intensities are usually moderate (0.4 to 0.6 inches per hour), but may occur for long duration resulting in 5 to 10 inches of rain per day.

The average annual maximum temperature is 58°F at Forks, with an average annual minimum of 40°F and mean of 49°F. The average frost free growing season is about 200 days.

Unusual weather conditions are a frequent occurrence along the Pacific Coast. Winds of 70 miles per hour occur almost annually, frequently causing extensive blowdown of trees.

The central core of the Olympic Peninsula is made up of the very rugged Olympic Mountains which are surrounded by a glacially reworked, almost level, lowlands or coastal plain. Bedrock of the Olympics consist of a volcanic horseshoe-shaped formation extending from Neah Bay east along the north sides of the Olympics, south along Hood Canal and then west to just south of Lake Quinault. The main Olympic Mountains are comprised of a sedimentary deposit or Tertiary origin.

A large variety of soils have formed from glacial materials with the type of soil influenced by the degree of compaction, slope and internal drainage. Alluvial soils of a variety of textures occupy terraces and valley bottoms adjacent to major rivers.

The hydrologic regimes of the low elevation forest basins of the Western Olympics, are typical of the rainfall zone with summer lowflow in rainless periods, and peaks in winter. Average annual runoff varies from 60 inches at lower elevations to 140 for the mid-elevations. Major rivers flowing from high snowfall zones of the interior Olympic Mountains have runoff of 160 to over 200 inches per year.

Coastal Washington and Oregon

This subregion essentially drains the western side of the Coast Range. Valleys are typically water eroded, with very limited glacial activity in the headwaters of a few higher elevation streams. Vegetation is somewhat similar to that of the Western Olympics, with increasing amounts of Douglas-fir farther south.

In this zone, western hemlock is considered the climax species. Large areas of the zone, however, are dominated by second growth and some old-growth Douglas-fir forests. Much of the subregion has been logged, or logged and burned, during the past 150 years. Major forest species are Douglas-fir, western hemlock, western redcedar, grand fir, Sitka spruce (near the ocean), and western white pine. In Oregon, near the southern limits of the zone, incense cedar, sugar pine and occasionally ponderosa pine occur. Near the upper elevational limit of the zone, Pacific silver fir occurs in mixed stands with western hemlock. Important hardwoods include red alder and black cottonwood in northern portions of the zone, with increasing amounts of big-leafed maple, Oregon ash, madrone, white oak and tan oak in southern Oregon.

The maritime climate of the Pacific Coast prevails throughout this zone. Annual precipitation averages 60 to 70 inches near sea level in southern portions of the zone; to 80 to 90 inches in southwest Washington. Near the crest of the Coast Range, average annual precipitation varies from 100 to 200 inches, depending largely on elevation. Maximum rainfall rates are moderate (0.4 to 0.6 inches per hour), with 4 to 6 inches per day total.

Mean annual temperatures range from 53°F near sea level in Oregon to 50°F in the Grays Harbor area of Washington. Average annual maximum temperatures range from 61°F in the south to 59°F in the north. Average annual low temperatures show about the same spread, with 45°F in the south and 42°F at Grays Harbor. The frost free growing season varies from about 200 days in Grays Harbor to over 300 days in the south.

The Coast Range from the Willapa Hills in the north to Coos Bay in the south is a complex of volcanics and sedimentary depositions (with certain interrelated volcanics).

Land forms show the dominating effect of high rainfall from prevailing western winds. Valleys are typically V-shaped with steep side slopes and active erosional processes.

Many areas have well-drained forest soils which are relatively heavy-textured, and with a very high surface organic matter content. On steep mountainside slopes, soils tend to be shallower, with a stony loam texture.

The hydrologic regime of Coastal Washington and Oregon is very similar to that of the Western Olympics. Rainfall predominates with maximum runoff occurring in December and January, the months of highest amounts of precipitation. Runoff can be highly variable from year to year. Average annual runoff varies from 40 inches to 80 inches in southern portions of the Coast Range to 120 inches in northwest Oregon, and the Willapa Hills of southwest Washington. Coastal areas of Washington and Oregon have very high water yields, with very dynamic river channels.

Klamath Mountains

The Klamath Mountains of southwest Oregon have been separated as a subregion based on their complex geology and related problems of mass movement, surface soil erosion and forest regeneration following timber harvest. The complexity of the subregion is somewhat indicated by the annual precipitation patterns, which vary from 100 to 200 inches along the coast to 20 inches in the interior valleys.

The forest types in the mountainous zones have been termed generally mixed conifer, which includes Douglas-fir, sugar pine, ponderosa pine and incense cedar, with a significant component of white fir and grand fir. On the ocean side of the Coast Range, redwood, Sitka spruce and western hemlock occur. Their occurence is confined to the mild, humid climate fronting the ocean, and their distribution becomes very limited in the interior valleys. These stands contain very high quality trees, with some of the maximum recorded amounts of biomass per acre.

The Klamath region contains two contrasting climates. The coastal area is relatively wet, with very little year-round temperature change and considerable rain during the late fall, winter and early spring. Average annual precipitation varies from 100 to 200 inches at higher elevations immediately adjacent to the coast. Rainfall of 75 to 85 inches is common at sea level. The frost free growing season at low elevations is in excess of 300 days.

The interior valleys of the Umpqua and Rogue Rivers have a significantly different climate, as they lie in the rain shadow of the Coast Range. At lower elevations on the valley floor, average annual precipitation ranges from 20 to 35 inches. There is a gradual increase going both east and west to the Coast Range and Cascades.

Average monthly temperatures range from 35 to 40°F during the coldest months to around 70°F in the warmest months.

Geologically, the Siskiyou Mountains of this subregion are the oldest formation in Oregon. Terrain is very rugged and deeply dissected. Geologic formations are quite complex, with areas of deposition of volcanic tuffs and sedimentary rocks which have been subsequently metamorphosed. Other formations include a variety of granitics, diorites and pyorites.

Soils of the subregion fall into two main groupings. Those of the western portion are considerably wetter and more humid than those of the dry eastern condition. Parent materials for these soils include both sedimentary and igneous rocks. There are also major drainages which contain a variety of well developed alluvial soils on terraces. Soils of the eastern portion of the region are often continuously dry for long periods during the summer, relatively shallow and show less profile development.

Two major rivers (the Umpqua and Rogue) bisect the Coast Range. Their drainages have characteristics of both the coastal rainfall zone and the snowpack zone at higher elevations. Smaller streams with their basins totally within the coastal rainfall zone have peak discharges in December and January, at times of maximum rainfall. The Rogue River, gauged at an interior location, shows peak flows from February through May. Minimum flows occur in September and October. When the Rogue is gauged near the mouth at Gold Beach, it responds to the pattern of coastal rainfall, with peak flows occurring in January and minimum flows in September. Threefold variations in average annual yield are common for rivers in the Klamath region.

Puget-Willamette Trough

The general characteristics of the maritime climate and distribution of plant species are quite similar to the Coast Range, which forms part of this subregion's western boundary. However, the Coast Range provides a barrier for movement of air masses, resulting in a marked rain shadow effect along the eastern slopes of the Coast Range, and in many places in the valley bottom.

Throughout much of the Puget-Willamette Trough, western hemlock is considered to be the potential climax species. Currently, much of the zone has been logged and burned, or converted to agriculture. Douglas-fir continues to be the dominant species in many of the second growth stands. Northern portions of the subregion contain mixtures of Douglas-fir, western hemlock and western white pine, with western redcedar and Sitka spruce occurring sporadically, and Pacific silver fir at higher elevations.

Northern portions are strongly influenced by the rain shadow of the Olympic Mountains. The Dungeness Spit has less than 15 inches of average annual precipitation. Most of the Puget Sound lowlands average 30 to 40 inches. Similar precipitation patterns occur in the Willamette Valley. High rainfall (up to 200 inches) on the summit of the Coast Range decreases very rapidly to lows of 40 to 45 inches in the valley bottoms. Maximum rainfall rates are moderate, seldom exceeding 0.5 inches per hour and 2 to 4 inches per day.

There is an expected progression in mean temperature from north to south. Mean annual temperature at Bellingham is 49°F, with the warmest months, July and August, averaging 74°F maximum temperature. Coldest months are January and February, with mean average low temperatures about 30°F.

The current land form and many aspects of the soils reflect the dominance of Pleistocene glaciation and the effects of flooding and redeposition of materials.

The Willamette Valley is bordered on the west by a variety of sedimentary and volcanic rocks of Eocene age, including pillow basalts, conglomerates, sandstones and siltstones. Less resistant materials have eroded, forming a series of east-west valleys with resistant formations forming ridges as extensions of the Coast Range. The western margin of the Cascade Range is made up of marine sediments. Columbia River basalts occur on eastern portions of the subregion.

In the Puget Sound area, the soils and landform are dominated by erosional and depositional activities of the Vashon glaciation. Glacial deposits have been reworked by rivers, and in some cases till deposits have been severely compacted.

The extreme variability of soil parent materials of the Puget-Willamette Trough, combined with the effects of extensive glaciation and reworking by meltwater, produce a very complex pattern of soils. These range from very shallow residual soils to deep silty alluvials and lacustrine deposits in the valley floors. These soils generally have well developed forest floor layers with varying incorporations of organic matter.

The peak flows of the smaller streams with their watersheds completely within the subregion occur in December and January immediately after rainfall maximums and runoff varies from 5 to 15 inches per year. River systems draining the east slope of the Coast Range have average annual runoff from 40 to over 100 inches.

Most major rivers flowing west from the Cascade Mountains integrate the effects of the rainfall, warm snow and frequently the cold snow zone. The combined effects of rainfall and the warm snow zone usually dominate, with peak discharges occurring during December and January, and with lowest flows in August and September.

Western Cascades

This subregion has many features in common with the Coastal Washington and Oregon subregion.

The Western Cascades has been classified (Franklin and Dyrness 1973) as the Pacific silver fir zone. Forest composition varies widely depending on age, stand history and local habitat, usually consisting of western hemlock, Douglas-fir, western redcedar and varying amounts of western white pine, Englemann spruce and subalpine species.

The climate of the subregion is wetter and cooler than the adjacent lowlands with considerably more of the precipitation in the form of snow. The winter pack usually accumulates in depths of up to 8 to 10 feet at upper elevations and persists from late October until May. Average annual precipitation ranges from 70 to 90 inches or more with the maximum occurring in December and January (10 to 13 inches), and minimum amounts in July and August (1 to 2 inches). Maximum rainfall rates seldom exceed 0.5 inches per hour with daily accumulations of 3 to 5 inches.

Average annual temperatures of the zone are about 42°F, with average maximum temperatures in July of 72°F and average minimum temperatures in January of 22°F. The frost free growing season varies from 120 to 150 days per year.

The subregion could be divided into several units based on origin of geologic material. From Mt. Rainier south, volcanic rocks predominate. These are mainly andesite flows with intermixed breccias in Washington with similar young volcanics and pyroclastics in the Western Cascades of Oregon. The topography generally exhibits the effects of Pleistocene glaciation, but land forms are less rugged than those farther north due to less extensive glaciation. North, along the west slope of the Cascades from Mt. Rainier, bedrock is frequently much older sedimentary materials which have been extensively folded and metamorphosed. Granitics occur in some areas, and major volcanic peaks occur in the southern portions.

Soils are formed from glacial deposits, reworked by rivers and residual soils. Very shallow soils grade into Lithic soils and wetter locations into Aquic soils. To the south, soils are dominated by ejected volcanic materials and glacially reworked soil parent material. The central portion of the Western Cascades in Oregon is predominately pyroclastics. These include tuffs, breccias and agglomerates. Glaciation and erosion have resulted in steep slopes and rugged topography. Southeast portions of the subregion tend to have large amounts of pumice and ash as a soil parent material.

The hydrology of the Western Cascade subregion matches the regime of the warm snow pack zone. An early peak discharge frequently occurs in

December and January coincident with maximum rain in lower elevation tributaries. Another peak occurs in late March or early April as snow melts at higher elevations. Annual runoff varies from 30 to 60 inches.

Eastern Cascades - North

Douglas-fir is the dominant and probably climax species in the more mesic habitats of this zone, giving way to ponderosa pine at lowest elevations. The forest composition varies widely but generally consists of Douglas-fir mixed with western hemlock, Engelmann spruce and western redcedar in higher elevation valleys, with extensive areas of lodgepole pine. In some areas, western larch and ponderosa pine become significant. Moist stream bottoms frequently contain significant amounts of grand fir.

The climate of the forest zone varies from the moist subalpine snow zone at higher elevations to the arid, ponderosa pine/grass type at low elevations. The Cascade Range forms a barrier to the easterly movement of moist air from over the Pacific, resulting in greatly reduced annual precipitation. The combination of the Cascades and Rocky Mountains forms a trough for north-south movement of air masses, resulting in seasonally very warm or cold conditions.

Seventy-five percent of the annual precipitation occurs between late October and early March. During this period, the bulk of the precipitation occurs as snowfall. Through much of the zone, annual precipitation averages 25 to 40 inches.

Extremes in temperature are common throughout the zone. Maximum summer temperatures are frequently in excess of 100°F, with minimum temperatures ranging from 10 to 30°F or more below 0°F. Average annual temperature for much of the zone varies from 45 to 50°F. The growing season ranges from 130 days in the north to 150 days in the south.

Movement of moist air masses over the Cascades during the summer frequently result in intense thunderstorms, which can yeild maximum rainfall rates of 6 inches per hour for short duration (5 to 10 minutes). Such storms produce flash floods and mud flows from localized forest drainages, but usually cover a limited area.

The geology of the Eastern Cascades is similar to that of the west side. Pleistocene uplifting exposed large areas of intruded granitics, including granodiorite, with metamorphosism of these formations into gneisses and schists. A large area of Cretaceous sedimentary rocks (Swauk sandstones) occurs between the acid igneous granodiorite types (Chelan Batholith) to the north and the basic igneous Columbia River basalt flows to the south. This formation has been steeply tilted in places, giving rise to highly erodible soils. Topography of the Columbia River basalts is considerably more gentle than granitic formations farther north. Inherently, unstable soils develop from granite and granodiorite parent materials. Soils formed from Swauk sandstones are also quite unstable, while soils formed on basalt tend to be more stable.

The Eastern Cascades are predominately in the hydrologic regime of the cold snow zone. Snow accumulates throughout the winter, to melt during late spring and early summer. Low flows occur during the coldest portions of the winter (January and February). High snow pack zones of the alpine and subalpine produce 60 to 100 inches of runoff per year. Lower elevations and watersheds with south exposure tend to produce peak discharge earlier in the melt season (March and April) as compared with higher elevations and north-facing slopes. Major floods of this subregion occur as a result of delayed melt, with synchronization of melt from a wide range of elevational zones and heavy, late-spring rainfall (4 to 6 inches in 36 to 48 hours).

Eastern Cascades - South

The northern portion of the eastern slopes of the Cascades varies from predominately Douglas-fir/ponderosa pine to a grand fir/Douglas-fir type. Other species include lodgepole pine and western larch. White fir and sugar pine occur in southern portions of the zone in Oregon, with significant amounts of western hemlock and western redcedar in localized habitats.

The climate of the Eastern Cascades - South is essentially a continuation of that in the Eastern Cascades - North. Precipitation averages 60 to 80 inches annually at upper boundaries of the subregion, with 25 to 30 inches in lower elevations. About two-thirds of this precipitation occurs in a five-month period between November and March, mainly as snow.

The mean annual temperatures tend to vary from 45 to 50°F. The frost free growing season ranges from 90 to 120 days.

Most of the terrain is relatively gentle, interrupted at intervals by glaciated river channels. The area is dotted with volcanic peaks and cones of varying age, size and elevation. Geologically, portions of the area are very young, with recent lava flows. Locally, glacial deposits are abundant and major mountain peaks are typically mantled with snow. Valley walls are frequently quite steep, with depositions of till and alluvial material in the valleys. Soils of the subregion are generally quite young and erodible.

The flows of the major rivers draining eastern slopes of the Cascades parallels that of the cold snow regime, with peak discharges in late May and minimum flows during the coldest months, January and February. Water yields vary from 40 to 60 inches at higher elevations to 10 inches or less near the forest-grass boundary. Over extended areas surface waters are extremely sparse. The Deschutes River combines the drainage of an extensive area of the zone in Oregon.

Blue Mountains

This subregion is discontinuous with the balance of the forest zones of eastern Oregon and Washington in that it is separated by the interior Columbia Basin of Washington and the high deserts of Oregon.

The Blue Mountains include both the ponderosa pine type and the grand fir/Douglas-fir type, as defined by Franklin and Dyrness (1973). Climax ponderosa pine is widely distributed in northeast Oregon and southeast Washington at the boundary between the sagebrush-grass zone and the forest zone. The upper limits of the ponderosa pine forest grade into

Douglas-fir, grand fir and white fir depending on locale. Lodgepole pine also occurs in association with ponderosa pine/lodgepole pine on the more mesic sites, while drier sites are occupied by ponderosa pine. Other mesic sites are frequently occupied by quaking aspen.

The climate of the Blue Mountains is dominated by Pacific maritime air masses moving eastward. Annual precipitation varies from 12 inches at lower elevations to about 80 inches at the crest of the Wallowa Mountains. The major portion of precipitation occurs as snow, with amounts exceeding 150 inches at higher elevations. The frost free growing season ranges from 100 to 140 days per year, with temperature extremes similar to those of the eastern slopes of the Cascades.

The eastern portions of the Blue Mountains span a variety of rock types. Permian formations consist of schists, limestones, slates, tuff and chert. Sedimentary formations also occur intermixed, but are discontinuous due to erosion. Certain portions of the Wallowa Mountains appear to be extensions of the granitic formations of the highly erodible Idaho Batholith. Other portions have recent depositions of Miocene lavas. Widespread glaciation occurred during the Pleistocene, with typical moraines, deposits and outwashes. Limestone, mudstone and sandstone of Paleozoic formations occur in the western region, and are some of the oldest formations in Oregon.

The Blue Mountains have been covered frequently with ash and fine pumice as aerial deposits. Subsequent erosion has removed much of the ash from south-facing slopes. Reworking by wind has also been common, with loess deposits.

The hydrologic regimes of streams of the Blue Mountains closely parallel those of the cold snow zone. Snows accumulate during winter months to be released as snowmelt from March through May. Annual water production is relatively low, with much of the Blue Mountains yielding 1 to 10 inches per year of runoff. Higher elevation snow packs in the Wallowa Mountains average 30 to 40 inches of runoff.

Okanogan Highlands

The Okanogan Highlands contain the most extensive area of ponderosa pine timber type in the state of Washington. Forest types vary from pure ponderosa pine at lower elevations in mixture with sagebrush and bitterbrush, to ponderosa pine, grand fir and Douglas-fir mixtures on gentle north slopes. More mesic sites include significant amounts of western hemlock and grand fir. Lodgepole pine frequently occurs in extensive pure stands following fire. Ground cover of pine grass and elk sedge are common.

Precipitation is relatively consistent throughout each month of the year, with the driest months of July and August receiving about half the rain (1 inch) of the amount received in the wettest months of December and January (2.1 inches). Many areas have more growing season rainfall than areas in the Eastern Cascades subregion with 70 to 90 inches of annual precipitation. This growing season rainfall is able to sustain good forest growth in 10 to 20 inches of average annual precipitation.

Temperatures of the Okanogan Highlands are very similar to those of the Eastern Cascades - North. Mean annual temperatures vary from 50°F at Grand Coulee Dam to 47°F at Laurier. The frost free growing season varies from 100 to 128 days per year.

Land form is in considerable contrast to many other subregions of the northwest. Glacial drift and reworked deposits are found throughout the area. Bedrock geology is complex with rocks of the Palezoic formation including quartzite, graywacke, slate, greenstone and some limestone. Granitic rocks of the Mesozoic are abundant, including some granitics and granodiorite. Limited areas of Tertiary deposition occur adjacent to major river valleys, including andesite and basalt.

Soils are equally complex in that recent deposits of ash have been reworked through erosion, providing a host of soil parent materials of widely varying textures. Soil erosion potential is relatively low as topography is usually gentle. Soils are noncohesive, however, and quite erosive, so disturbance of vegetation on the steeper slopes can result in significant soil movement from both high intensity rainstorms and snowmelt.

The subregion is relatively arid with much of the areas receiving less than 20 inches of annual precipitation. Low precipitation plus very pervious soils results in a very low density stream network. Annual runoff ranges from zero to about 10 inches, with the bulk of the area averaging 5 inches.

Northern Idaho

There is a progression of forest types from lower elevations on the west to higher elevations in the mountain ranges bordering the subregion in the east. Ponderosa pine intermixes with Douglas-fir and lodgepole pine at lower elevations. With increasing elevation and annual precipitation, western larch, western white pine, grand fir, Engelmann spruce and subalpine fir become important. Interior western hemlock and western redcedar sometimes form climax stands.

The climate of the Northern Idaho subregion is typical of that of the cold snow hydrologic regime. Annual precipitation varies from 15 inches at lower elevations at the boundary of the commercial forest to 50 inches near the summit of the Selkirk and Bitterroot Mountain Ranges. The driest months are usually July and August, with the wettest period usually in December and January. About 70 percent of the annual precipitation occurs during the snow accumulation season of October through March.

Warmest areas are at the lower boundary (near Spokane) where mean annual temperatures are approximately 48°F. At the higher elevations, there are significant decreases in temperature. At Mullen Pass (6,000 feet), mean annual temperature is 37°F, ranging from a monthly maximum temperature of 69°F in July to a minimum of 14°F in January. The frost free growing season varies from less than 90 days at higher elevations to 150 days at lower elevations in the ponderosa pine zone.

Northern portions of the subregion show the dominating influence of Pleistocene glaciation, with rolling topography and deep glacial deposits. Glacial erosion intermixed with Tertiary lava flows leave a complex of deep lake deposits with exposed basalt. Erosion of the Kaniksu Batholith formed the Selkirk Mountains. An extensive area of Columbia River basalts occurs in the vicinity of Lake Coeur d'Alene. These flows overlay the Precambrian sedimentary rocks which form the Bitterroot Range. Considerable metamorphism occurred where the basalts contact the northern boundary of the Idaho Batholith.

Lithic soils occur on eroded granitic materials of the Kaniksu Batholith. The young Columbia River basalts also have an eroded phase which classes as Lithic soils or undeveloped soils. The effects of glaciation have generally removed the weathered granitic surface materials. Formations of Northern Idaho are highly erosive, particularly those farther south in the Idaho Batholith. Extreme care must also be taken on the Palouse loess soils, which occur in the western portion of the timbered zone.

The major drainages include the Spokane River (including the Coeur d'Alene and St. Joe), the Clearwater, and portions of the Salmon, Kootenai and Clark Fork of the Flathead. Average annual runoff varies from less than 10 inches at lower elevations in the ponderosa pine zone to about 40 inches at highest elevations in the Selkirk-Bitterroot Mountains.

Intermountain

Glaciation effects in the Intermountain subregion are limited to higher elevations where alpine glaciers locally affected the soils and topography. Parent materials of much of the area are Precambrian, metamorphics and other intrusives. Precambrian sedimentary rocks also occur in a complex intermixture.

Forest types are typical of the ponderosa pine/Rocky Mountain Douglas-fir forests which cover much of northeast Washington, Idaho and Montana. Ponderosa pine is dominant and climaxes at lower elevations in mixtures with Douglas-fir. With increasing elevation and more humid conditions, western larch, Engelmann spruce and lodgepole pine make up significant components of the forest stand. Localized in humid river bottoms, grand fir is also an important species.

The forest zone occupies a precipitation range from 15 inches at lower elevations to 50 inches of annual precipitation at higher elevations in the Salmon River Mountains. Maximum precipitation occurs in November through February. Snowfall accumulates to maximums of 100 to 200 inches at higher elevations in the mountains.

Temperatures show the expected inverse relationship with elevation for mean annual, highs and lows. The frost free growing season ranges from 140 days at lower elevations to less than 90 days at the upper limits.

The Intermountain subregion is the location of the Idaho Batholith, a Cretaceous granitic intrusive that has weathered in place for the last 70 to 90 million years. It is an extremely large outcrop covering over 14 thousand square miles. While uniform in its origin, it contains a host of grain and crystal sizes in various areas. Most grain sizes are relatively large, weathering to a very coarse-textured soil. The soil texture in combination with relatively steep topography has resulted in one of the most erosive geologic formations in the western United States.

The eastern boundary of the Intermountain subregion in Idaho is formed by the Beaverhead, Lemhi and Lost River Ranges. These ranges are Precambrian and Paleozoic sedimentary rocks. Older rocks of the Precambrian include slates and mudstones, while rocks of the Paleozoic are predominately limestones and dolomites.

Soils of the Intermountain zone are highly erosive. In areas of gentle topography, forest floor layer can build up sufficiently to initiate processes of soil formation. In general, erosion and limited accumulations of forest floor material have resulted in extensive areas of immature soils.

The hydrologic regime of the Intermountain subregion closely parallels the cold snow zone. Snow packs accumulate throughout the winter, to be released as snowmelt with peak flows occurring in late May. South exposures and lower elevations melt in late March and April with higher elevations and north exposures melting later. Average annual runoff varies from insignificant amounts at lower elevations in the ponderosa pine zone to maximums of 40 inches in the higher mountain ranges of the Bitterroot-Beaverhead.

Regional Fisheries Resources

Commercial and sports fisheries resources of Region X are dependent on aquatic and estuarine habitats within, or affected by, the commercial forest zones for reproduction and rearing. The more important species utilizing these environments are: pink (humpback) salmon, chum (dog) salmon, sockeye (red) salmon, Chinook (king) salmon, coho (silver) salmon, rainbow and steelhead trout, cutthroat trout, and Dolly Varden (char). The spawning habitats of reproducing species consists of suitable gravel with a continuous supply of high-quality water with a highly dissolved oxygen content. Spawning beds must be protected from physical damage by floating debris or depositions of sediment while eggs, or alevins (recently hatched fish), are in the gravel. The quality of the aquatic environment is also very important year round for the rearing and growth of juvenile fish.

While the life cycle habits of many of the species have certain aspects in common, there are sufficient differences in their use of the freshwater environment that a distinction should be made between certain species. Pink and chum salmon utilize freshwater only, for spawning and egg incubation. These species typically spawn low in streams very close to salt water in summer and autumn, with fry emerging from stream bed gravels in spring. Fry may migrate to salt water immediately, or remain in the stream for a very short time. The life cycle in the ocean requires one-and-a-half to four-and-a-half years, then adults return to their streams of origin to spawn. Pink and chum salmon are important throughout coastal Alaska, Puget Sound and in streams of Washington and Oregon.

Sockeye salmon generally require a lake in the river system used for reproduction. Adults move upstream to the lake and into the tributaries where they spawn. The emerging fry then migrate to the lake where they spend one or more years as residents. On reaching migratory size, juvenile sockeye salmon migrate to the ocean in the spring of the year where they feed and grow to mature adults, usually after one-and-a-half to three-and-a-half years. The very red flesh of the sockeye salmon makes it one of the most prized commercial species. It is still a particularly important species in Washington and Alaska and was once important in the Columbia River system, but has now declined significantly there due to habitat changes.

Chinook and coho salmon and steelhead trout utilize rivers throughout coastal Alaska, Washington, Oregon, Idaho and northern California. Chinook salmon are the largest of the Pacific salmon, and generally favor larger river systems. There are runs in most of the large rivers from the Yukon south to San Francisco Bay. Three races of Chinook salmon are commonly recognized based on the time of entry into fresh water (spring, summer or fall). Spring Chinooks enter these streams as early as March and April, while later runs peak in mid-July. A fall run enters the streams from September into December. Coho salmon have a much wider range of suitable stream habitats as they will enter both large and small streams for spawning. Coho and most Chinook juveniles spend one or more years in fresh water before reaching migratory size, and returning to the ocean (certain races of Chinook emigrate to sea after only three months). They will then spend one or more years in the ocean completing their life cycle to return to spawn in fresh water.

Rainbow trout (steelhead) and cutthroat trout also have similar life cycles, entering fresh water from the ocean to spawn, with juveniles spending differing times in the fresh water. The primary difference between trout and salmon in life cycle, is that trout do not necessarily die after spawning and may return to spawn in fresh water several times.

Most major water bodies in Region X either have natural populations of fish that are important for sport or commercial use or have introduced species. Physical barriers have caused natural landlocking of both the salmon and trout in particular river systems. Landlocked sockeye salmon (kokanee) are important in many of the larger lakes tributary to the Columbia River.

CHAPTER 3

FOREST PRACTICES IN THE PACIFIC NORTHWEST

FOREST PRACTICES IN THE PACIFIC NORTHWEST

Cutting Practices

THINNING

Cuttings which are made in immature stands to stimulate growth of the remaining trees in order to increase the total wood yield are termed thinnings (Smith 1962). Although many types of thinning are recognized in the practice of silviculture, in general two types of thinning receive the greatest use in the Pacific Northwest: precommercial thinning and commercial thinning. Precommercial thinning is most effectively applied as a single thinning when trees are small - perhaps 10 to 15 feet in height (Carter et al 1973). Commercial thinning, on the other hand, is practiced on older stands for which the thinned trees have marketable value as pulpwood, poles or sawlogs.

Precommercial Thinning

The basic objective of precommercial thinning is to increase merchantable yields by concentrating productivity of the site into fewer stems per acre (Miller 1971, Carter et al 1973). Although the principal objective of precommercial thinning is such stocking control, thinning is also valuable for the control of mortality due to insects and disease (Nelson 1971). Precommercial thinning is accomplished either with chemicals or by mechanical methods, primarily power saws.

One of the problems associated with precommercial thinning is the treatment of slash. It is reported that perhaps one-fifth of the cost of precommercial thinning on the National Forests of Region 6 is attributable to slash disposal requirements (Robertson 1971). The quantity of slash generated during precommercial thinning is highly correlated with the age of the stand; i.e., the larger the trees, the larger the amounts of slash (Donald 1975).

Commercial Thinning

Commercial thinning in the Pacific Northwest is practiced in the management of a number of the more valuable species, including Douglas-fir (Reuhema and Pinaar 1973), western hemlock (Molmberg 1965), and ponderosa pine (Barrett 1968). The objective of commercial thinning in these stands is to provide more desirable tree spacing and to concentrate growth on the remaining trees as a means of increasing the total yield of wood. The age at which stands are thinned is determined both by tree growth rate and market demand for specific types of wood products.

Many foresters feel that dense stands which will respond to thinning on poorer sites should receive primary emphasis for thinning (Barrett 1968). Others prefer to concentrate on stands that will respond the most quickly to treatment.

In contrast to precommercial thinning, commercial thinning requires entry into stands with logging equipment for removal of felled trees. Both cable systems and tractors are used in the Pacific Northwest. The soil disturbance which occurs can result in surface erosion and thereby impact water quality. In addition slash produced during commercial thinning, if not treated properly, can adversely affect water quality.

The effect of commercial thinning is nearly always to improve the general quality of a stand. Rates of growth in diameter and height, primarily the former, usually increase. Because the less vigorous trees are customarily cut during thinning, future stand mortality is reduced (Smith 1962). Consequently, the quantity of defective material in the stand at final harvest is lowered and reduced quantities of slash can be expected. This tends to reduce somewhat the slash management problems at final harvest and, consequently, to lessen the water quality impact.

Both crawler and wheel tractors are used for thinning throughout the region and in general are restricted to topography of moderate slope (less than 35 percent). The use of tractors requires the construction of skid roads as well as landings. The resultant exposure of mineral soil and soil compaction (as will be discussed in Chapter 4) can contribute to soil erosion problems.

Smith (1962) has pointed out that thinning increases the runoff of forested watersheds mainly by the temporary opening of the crown canopy, which causes a reduction of interruption of precipitation. More water reaches the soil and less is lost by direct evaporation. Goodell (1952) found that the yield of water might be increased by 15 to 20 percent as a result of heavy thinnings in young lodgepole pine stands. This could well increase erosion, but site-specific data is not available to demonstrate the runoff/erosion impacts of thinning.

Commercial thinning of stands located on steep slopes and therefore unsuitable for tractor operation would be best accomplished with either aerial or cable logging systems. However, high costs and low production preclude the use of aerial systems for thinning. Although several cable systems can be used for commercial thinning, skyline systems equipped with a carriage capable of lateral yarding to the skyline offers several distinct advantages (Binkley and Williamson 1968). Logs were yarded laterally to the skyline and longitudinally with one end in contact with the ground. The extent of soil disturbance engendered should be less with this system than that caused by tractor logging.

Burke (1975) has pointed out that a running skyline equipped with a slackpulling carriage with a lateral yarding capability of 150 feet can be used for partial cuts. Aulrich _et_ _al_ (1974) compared tractor and skyline logging for thinning young Douglas-fir stands. Although no soil compaction was found in skyline units, increases in soil density were detected in tractor units. (Tractor logging also left less slash and therefore less potential for organic leachates.) Because tractor logging left less slash, a reduction in water quality impact resulting from slash would be expected.

FINAL HARVEST

In general, four silvicultural systems have been used for the management of coniferous forests in North America: shelterwood, seed tree, clearcutting, and selection. The selection method leads to uneven-aged stands, whereas even-aged stands result from use of the clearcutting, seed tree and shelterwood methods.

Of the four silvicultural systems in use, clearcutting and selection cutting are used predominately in the Pacific Northwest. Clearcutting prevails on the west slope of the Cascades, throughout the mixed conifer stands of eastern Washington and Oregon, and in the white pine stands of northern Idaho. Selection cutting is used primarily for the harvest of ponderosa pine. There are exceptions to this general pattern; however, Williamson (1973) has reported limited success with shelterwood cutting of Douglas-fir at the higher elevations in western Oregon. Also, partial cutting of old-growth lodgepole pine stands is successful under some circumstances (Alexander 1972). Williamson (1966) has suggested that adequate regeneration of well-stocked stands of western hemlock can be assured under any one of a broad range of shelterwood densities.

Shelterwood

The shelterwood system requires the removal of the stand in a series of cuts. Although some natural regeneration normally occurs under the cover of a partial forest, it is common practice to artifically regenerate shelterwood cuts. This system is especially well adapted to species or sites where protective cover is needed, usually for reproduction purposes, or where the shelterwood gives the regeneration an advantage over undesirable competing vegetation. Shelterwood cutting is sometimes used for special aesthetic management purposes (for example, in or near campgrounds).

Seed Tree

The seed tree method requires the removal of nearly all the timber of an area, usually in one cut. Consequently, the impact on the site is not unlike that of the clearcutting method. Specially selected, vigorous, wind-firm trees of the desired species are left scattered over the area to provide a natural source of seed (USFS 1973). The very nature of the method requires that it be applied only to species whose seed is wind disseminated (Smith 1962). Because the size and frequency of seed crops are difficult to predict for many species, the seed tree method has not proven to be particularly satisfactory for obtaining stand regeneration. The seed tree method has limited applicability in regenerating coastal Douglas-fir because of the high risk of wind damage (Smith 1972).

Clearcutting

Clearcutting involves the complete removal of the timber stand over a given area in a single cut. This system requires the use of intensive management practices, including erosion control, in site preparation and regeneration of the new forest. Regeneration can be achieved through natural seeding. However, the larger clearcuts frequently must be regenerated artificially to avoid extended periods of exposed soil surface (USFS 1973). Hand planting of nursery stock is considered to be the most reliable method for regeneration.

Clearcuts range in size from a few to several hundred acres. The areas range in shape from small nearly square patches (sometimes called "patch cuts") to long narrow strips sometimes parallel but more often perpendicular to the contour. Clearcutting in alternate strips is sometimes practiced (Smith 1962). Recently, attempts have been made to blend clearcuts with natural openings in the forest, including avalanche zones at the higher elevations (USFS 1974).

Clearcutting is one of the most economic harvest methods from the standpoint of timber marketing, since it permits intensive use of both labor and equipment over a short time period. Clearcuts can be yarded with any logging system, although cable systems are perhaps used more extensively, particularly in western Oregon and Washington. A wide range of mechanical equipment for preparation of the cutover site for either seeding or planting is available. For the most part, equipment for site preparation is restricted to use on moderate and gentle slopes. Theoretically, areas suitable for clearcutting can be harvested and regenerated in a relatively short period of time.

Clearcutting is particularly appropriate for old-growth stands as well as for disease- and insect-infested stands. Large quantities of slash frequently accumulate from clearcutting old-growth stands as well as from stands characterized by a high degree of mortality. Treatment of the slash is essential in order to avoid water quality damage as well as to reduce the fire hazard and minimize insect infestations.

Because practically all of the vegetation is removed from an area during clearcutting, the site is exposed to more intense levels of radiation than previously, and site desiccation (rapid losses of soil moisture) is sometimes a problem. A minimum cover of vegetation remains to receive and disperse rainfall. The area is also more subject to wind action and the timber in adjacent areas is more subject to windthrow. Regardless of the species involved, site regeneration can be a problem, particularly at higher elevations on south- and west-facing slopes.

Selection Cutting

Selection cutting in the Pacific Northwest is practiced largely in the ponderosa pine stands located primarily in eastern Washington, but also in Oregon and Idaho. In general, two variations of the system are practiced: (1) single tree selection and (2) group selection. Single tree selection leads to an increase in the proportion of shade-tolerant species. Group selection, on the other hand, tends to maintain a higher proportion of the less shade-tolerant species. For the management of ponderosa pine forests, however, several modifications of the selection method have been developed, including maturity-selection, improvement-selection, sanitation-salvage, and unit control area. Smith (1962) summarizes the various forms of selection cutting as follows:

> "The maturity-selection method is aimed mainly at making best use of the growing stock in a rather passive manner: improvement-selection at the active upgrading of the stock; sanitation salvage, at overcoming catastrophic losses; and unit area control, not only at reproducing stands but also at establishing an efficient arrangement for future management."

WATER QUALITY IMPLICATIONS

The water quality impacts of precommercial thinning are, for the most part, indirect and minimal. Since precommercial thinning is usually accomplished manually, site disturbance is almost nonexistent. However, small quantities of slash are produced which introduce a fire hazard and also may harbor insects. Increased insect populations can lead to increases in stand mortality and can thereby add to the fire hazard. As will be emphasized later, fire exposes the soil surface and leads to increased rates of erosion; therefore, adequate slash treatments following precommercial thinning are necessary. The precommercial thinning of older stands will, in general, produce larger quantities of slash, thereby increasing the need for treatment.

Commercial thinning, in contrast, requires the use of tractors or cable logging systems for removal of felled trees. Furthermore, substantial quantities of slash can be generated. Normally, however, slash volumes are expected to be somewhat lower than that of final harvest.

The extent of site disturbance brought about by commercial thinning should, in general, be less than that of final harvest, since lower volumes of material are being removed. Nonetheless, mineral soil will be exposed and the amount of precipitation which reaches the ground will be increased. Consequently, the probability of an undesirable amount of erosion can be expected to increase. However, under normal circumstances and with adequate precautions, the remaining stand and associated understory should limit the resulting surface erosion. The evidence available suggests that tractor logging is more destructive to the site than cable logging with the difference accentuated on steeper sites.

Although the shelterwood method offers many water quality advantages, It also has disadvantages. There is no practical way to use the shelterwood system in many old-growth stands or in stands where mistletoe is a problem. Damage to the newly-established stand is almost unavoidable during the final removal cut, particularly in old-growth timber on steep slopes. Slash management is more difficult because of the need to protect the residual stand. Perhaps most important from the standpoint of water quality, however, is that several entries into the stand are required. Consequently, the site is disturbed on a number of occasions and the period of surface erosion risk is extended.

The impact of clearcutting (including seed tree) on water quality is associated primarily with: (1) site exposure and soil disturbance, and (2) the presence of large quantities of forest residue.

Some soil disturbance occurs with all types of harvesting equipment used on clearcuts. Current evidence, however, suggests that tractor logging is more disruptive than cable logging (see Chapter 4). The added exposure of the site to the extremes of climate brought about by clearcutting can result in accelerated surface erosion if adequate measures for site protection are not taken (Smith 1962). Because large quantities of residue are usually generated by clearcutting, particularly of old-growth stands, debris can accumulate in ravines and streams. An increase of organic materials in the runoff water and the failure of debris dams which may lead to stream scouring can result.

The impact of selection cutting on water quality is associated with site disturbance and, to a much lesser extent, with forest residues.

Because of the low quantities of slash normally produced during selection cutting, particularly on low-volume ponderosa pine stands, residues are rarely a problem insofar as water quality is concerned. Soil disturbance, however, can be more of a problem. Selection cutting requires entry into the stand more frequently than clearcutting. Cable logging systems including jammers as well as both crawler and wheel tractors are used in selection cuttings of ponderosa pine. As a consequence, soil disturbance and soil compaction can be a problem, praticularly on steep sites and erodible soils.

Regeneration Practices

REPRODUCTION

Artificial reproduction is obtained either by planting young trees or by applying seed, sometimes called "direct seeding." Natural regeneration of coniferous forests is obtained from seedlings which originate by natural seeding. In the Pacific Northwest artificial regeneration is practiced much more extensively than natural regeneration. The regeneration of stands in southeastern Alaska, on the other hand, is more dependent on natural seeding (Harris 1967).

Direct seeding offers many advantages such as lower cost, fewer organizational problems, and the possibility of seeding over longer periods of the year than planting (Smith 1962). Although labor and equipment are costly, the probability of survival is much better with planting than with seeding. Consequently, planting is practiced much more widely than direct seeding today in the Pacific Northwest and is considered to be the surest method for obtaining regeneration.

Natural regeneration following harvesting requires a source of viable seed. The size of the cutover area, topography, prevailing wind direction and many other factors have a significant bearing on the success of natural regeneration of clearcut areas (Harris 1967). Partial cuts such as selection cutting, offer marked contrast to clearcuts in that provision is made for a seed source in the immediate vicinity of the harvest area. Leaving a natural seed source on harvested areas, however, does not guarantee successful regeneration and/or stocking.

Seedbed preparation for natural regeneration is often accomplished as a result of logging and slash disposal. However, in many instances deliberately-planned additional site preparation work is also needed. The resulting soil disturbance and possible soil compaction from the use of heavy equipment on the site can have adverse water quality effects.

Some species will regenerate rapidly on cutover areas if the site conditions are at all conducive to their reestablishment. For example, provided that all critical environmental factors are favorable, Douglas-fir will regenerate naturally on many sites in the Pacific Northwest. On the other hand, natural reestablishment of Douglas-fir is difficult on many sites. Given the proper circumstances, ponderosa pine will regenerate naturally in many parts of its natural range. Nonetheless, there are many situations, particularly on drier, less fertile sites that are subject to extremes of temperature and radiation on which natural regeneration is difficult if not impossible to obtain.

Planting stock is grown in nurseries, with transplanting one or two years after seeding, depending on the species. Field planting is nearly always a hand operation, using either bars or mattock-type tools. Under certain conditions the power auger prepares satisfactory planting holes, speeds the planting operation and improves planting quality. In areas of gentle slope or where steeper slopes have been terraced, machine planting is sometimes practiced (Adams 1969). Both containerized seedlings and bare-rooted stock are used.

SITE PREPARATION

Both planting and direct seeding nearly always require some form of site preparation beforehand, including slash treatments and disturbance of mineral soil. As will be described in the section on Residue Management, slash burning is practiced throughout the region. Burning of slash exposes the soil, reduces the organic matter content and can thereby lead to increased rates of surface erosion. Lopping and scattering of slash and crushing in place are sometimes used and reportedly offer advantages in terms of seedling survival (Cochran 1973). The regeneration of old brush fields may require the use of herbicides and fire as a first step in site preparation. The conversion of brush lands as well as lands occupied by inferior species has been, and will continue for some time to be, a major management activity of significance to water quality in the Pacific Northwest.

Following slash treatment or removal of competing vegetation, some form of site disturbance is sometimes necessary to expose the mineral soil needed for direct seeding as well as for planting. Partial or complete removal of the layer of duff and litter is involved. On cut-over areas the disturbance brought about by the movement of logging equipment over the area is frequently sufficient. However, additional measures are sometimes needed to expose mineral soil, whether planting or artificial seeding is used (Adams 1969; Schultz and Biswell 1959; Foiler and Curtis 1973; Smith 1962).

In recent years, new mechanical methods of site preparation have been developed and old ones greatly refined. All sizes of tractors with various attachments, as well as specially-designed machinery prepare planting sites more efficiently and economically than was previously possible. Several years ago, Curtis (1964) itemized the kinds of disturbance that site preparing equipment can inflict on the ground or vegetation. The list is imposing and includes disking, furrowing, stripping, ripping, punching, slitting, dragging, chopping, tilling, churning, logging, and crushing. In addition, the list could have included plowing, scalping and terracing. During the last 10 years, most mechanical site preparation has involved scarification, stripping, or terracing.

Machine scarification is usually accomplished with a crawler tractor equipped with a toothed brush blade. The objective of scarification is to eliminate obstacles to planting such as heavy brush, slash and old stumps. An intermixing of litter and duff with mineral soil takes place such that soil adequate for regeneration is exposed. The litter and duff act to some extent as a mulch for retention of water and slow release of nutrients. If the volumes are excessive, windrowing of brush and residue may be essential. Burning of the windrowed material before planting allows additional planting space for seedlings, removes habitat for rodents, pests and insects, and minimizes the fire hazard for newly-established stands.

Dishpanning, a form of scarification, is accomplished with machine, usually a crawler tractor equipped with a blade. The vegetation is removed from a relatively small area a few feet in diameter preparatory to direct seeding or planting.

Hand scarification of a small area, approximately three feet in diameter is frequently practiced by crews before planting seedlings. Highly localized disturbance of this nature removes plant competition in the immediate vicinity of the seedling and also reduces soil moisture losses. Hand scarified spots are sometimes sloped from the edges to the center in order to trap and retain moisture.

Stripping is the removal of long strips of competing vegetation on narrow contour benches, incised across slopes by small tractors. These strips are usually too narrow to accommodate a planting machine, so hand planting is necessary. Contour strips are kept narrow to limit or control disturbance of the soil mantle and interruption of ground-water movement.

Terracing involves a more complete clearing of competing vegetation than stripping and is accomplished by constructing large contour benches that are commonly the width of a tractor. Packer (1971) reports that little erosion has resulted from terracing since its first use in southern Idaho. A U. S. Forest Service task force appraisal (1969-1970) on the Bitterroot National Forest found few signs of serious erosion on most of the terraced slopes but cautioned that long-run erosion could not be determined.

WATER QUALITY IMPLICATIONS

The burning of residues left after harvesting or of brush from old fields being prepared for planting can indirectly affect water quality. A number of researchers including Dyrness and Youngberg (1957) and Tarrant (1956) have reported that slash burning modifies soil properties in highly localized areas where burning is particularly intense. These areas, which usually occupy a relatively small part of a controlled burn, exhibit changes in soil structure, decreases in wettability, and loss of nutrients. Such occurrences have little overall impact on water quality when the area involved is minimized. However, large areas in which burning is intense could increase runoff, erosion and the nutrient loss to streams.

The exposure of mineral soil preparatory to seeding and planting has far greater potential for impacting water quality than burning. As is discussed in other portions of this report, exposed mineral soil can be eroded rapidly. Furthermore, dishpanning, scarification, stripping, terracing, and plowing all require the travel of heavy equipment over the site. Soil exposure and compaction can take place and intensify erosion processes. Sites at higher elevations, soils that are derived from igneous rock, and soils on steep slopes are particularly vulnerable.

Site preparation methods that reduce soil disturbance to a minimum commensurate with obtaining stand regeneration and which also minimize the use of heavy equipment on the site are preferable from a water quality standpoint.

Logging Methods

In the Pacific Northwest systems used for the movement of logs from the stump (point of felling) to a landing (point of concentration) can be classified as one of three major types: tractor, cable and aerial. Animal skidding is a fourth, but minor type. Tractor skidding is accomplished with either crawler or wheel type units, both of which are frequently equipped with auxiliary devices for reducing the extent of contact between log and ground (Pearce and Stenzel 1972). Cable logging, of which there are many forms, is a yarding system employing winches in a fixed position (USFS 1969). Aerial logging, a recent development in the logging industry, is accomplished with heavy-duty and medium-duty helicopters.

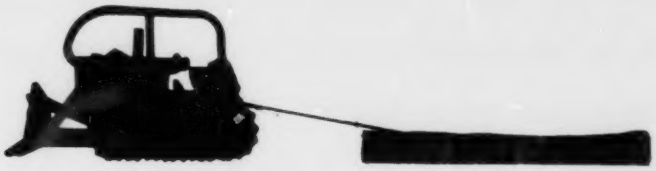
ANIMAL

At one time, skidding was accomplished entirely with animals, primarily mules, horses and oxen. Animals are still used but on a much restricted basis, primarily in the northeastern and southeastern parts of the United States, in Canada in situations where log sizes are small, and occasionally in the northern Idaho subregion on small private woodlots. Moderate slopes with favorable grade are essential. Maximum skidding distance rarely exceeds a few hundred feet and, consequently, a dense road system is required. The few instances for which data are available indicate that site disturbance during animal logging is substantially less than that brought about by tractor skidding, not including the road system effects (Pearce and Stenzel 1972).

TRACTOR

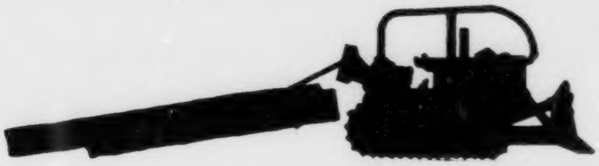
Crawler tractors, introduced to logging in the early 1930's, are now used throughout the Pacific Northwest. The slope distance from the outer boundary of the cutting unit to the landing (external yarding distance) is limited to approximately 300 feet and 20 percent slopes for uphill yarding. Maximum downhill yarding is limited to yarding distances of 800 feet on slopes of 35 percent (Studier and Binkley 1974).

Crawler tractors used for logging are normally equipped with a winch and wire rope (Figure 2). When yarding on steep, swampy, rocky or otherwise difficult terrain, the tractor can be located on stable terrain and the winch used to skid logs a short distance to the tractor. The winch can also be used to pull the tractor from terrain in which limited traction is available (Pearce and Stenzel 1972). Various attachments, primarily arches and sulkies, have been developed for tractors which reduce the degree of contact between log and ground. The arch, which is either track-mounted or an integral part of the tractor, is designed to raise the leading end of a tractor-skidded log (Figure 3). A tractor sulky or "wheeledarch" is similar to the arch. Track-mounted arches are reported to be 30 to 50 percent heavier than tractor sulkies. Consequently, the tractor sulky unit can negotiate steeper grades, which results in a higher potential for soil disturbance and erosion (Pearce and Stenzel 1972).



CRAWLER TRACTOR
GROUNDSKIDDING LOGS

FIGURE 2



CRAWLER TRACTOR WITH
INTEGRAL ARCH SKIDDING LOGS

FIGURE 3

Agricultural and industrial tractors were the first wheel-type units to be used for logging. During the 1950's, however, developmental work by several manufacturers was undertaken to produce rubber-tired wheel skidders designed specifically for logging.

Wheel skidders have the advantage of greater speed but the disadvantage of limited traction. They can be equipped with a light bulldozer blade, useful for clearing obstacles from skid roads and moving logs at the landing. Wheel skidders can be equipped with an articulated hydraulically operated grapple which lifts the leading end of the log free of the ground and reduces soil disturbance during skidding. Inaccessible logs can be winched short distances into position to be grappled and skidded.

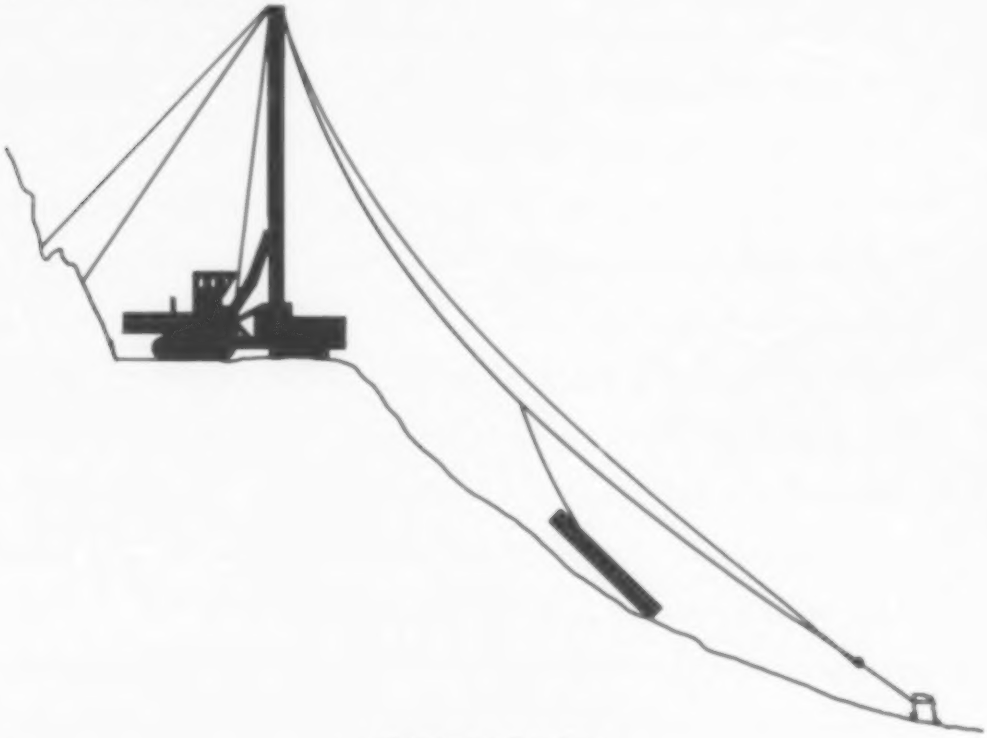
CABLE

Cable logging, of which there are many forms, is used throughout the Pacific Northwest. Cable systems are designed to yard logs from the felling site by a machine equipped with multiple winches commonly called a yarder. A wide range of systems are available today for logging both large and small timber.

Although originally used almost exclusively for yarding clear cuts, recent innovations have made cable systems highly suitable for yarding on partial cuts such as selection cuts. Cable logging is highly efficient for logging steep rough ground on which tractors cannot operate. Some cable systems can operate in any direction - upslope, downslope and along the contour. Most importantly, several studies, (Wooldridge 1960; Dyrness 1965; Aulerich et al 1974) have indicated that cable systems result in far less site disturbance than tractor logging and can operate on terrain for which tractors would be unsuitable due to the possibility of site disturbance. Depending on the system used, yarding distances of up to

4,000 feet are possible (Studier and Binkley 1974), which tends to reduce the required road density compared to tractor logging.

For many years cable logging systems could be classified as either high lead or skyline. Balloon logging, first introduced in North America in the 1960's, can be considered as a third type of cable yarding. The high lead system (Figure 4) moves logs from stump to landing by reeling in a wire rope called the mainline. The mainline is fastened to a block which is located well above the ground on a spar tree or steel tower.



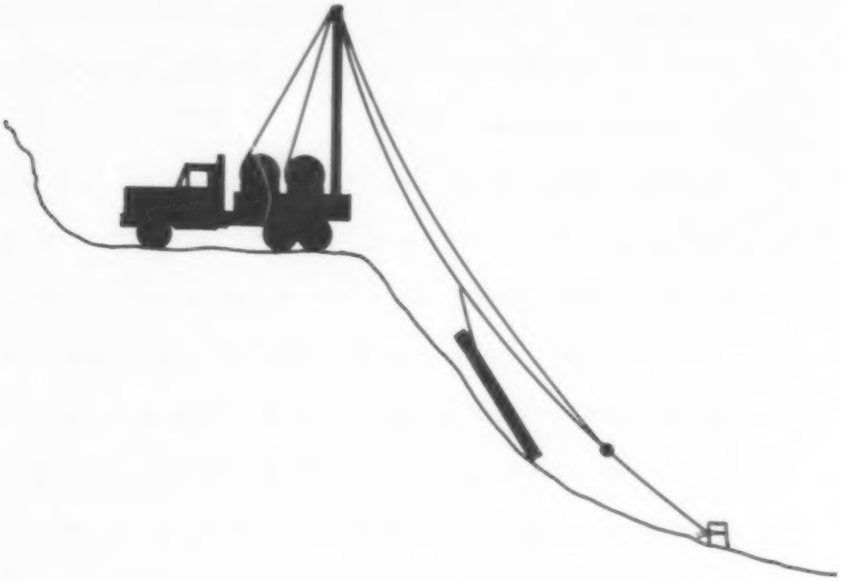
HIGH LEAD SYSTEM
GROUND SKIDDING UPHILL

FIGURE 4

Portable steel towers, ranging from 80 to 120 feet in height, are now used almost exclusively for high lead logging. The tower assists in providing lift to the leading end of the log in order to reduce friction between log and ground, overcome obstacles, and reduce the amount of soil disturbance. The maximum uphill yarding distance of high lead systems is approximately 1,000 feet; whereas downhill yarding is limited to approximately 500 feet (Studier and Binkley 1974; Binkley 1967). Although downslope and sideslope yarding are possible, control of log movement is minimal and severe site damage often results (Peters 1973). The system is suited only for clear cut logging.

The mobile shovel yarder or mobile logger is a modification of the high lead system (Studier and Binkley 1974). Usually track mounted, its mobility permits yarding partial cuts as well as clear cuts. Logs can be yarded perpendicular to the contour along parallel yarding roads and decked in windrows along the edge of the truck road. Consequently, landing size can be reduced with this system (Pearce and Stenzel 1972). The system is limited to uphill yarding for distances of 500-700 feet (Studier and Binkley 1974).

The Jammer (Figure 5) came into widespread use in northern Idaho and the Intermountain sub-regions following World War II (Pearce and Stenzel 1972). Jammers are either track or wheel mounted and are equipped with either a steel or wood boom. The units are equipped with either a one- or a two-drum winch. One drum is used to power a skidding line which is attached to the log; the other drum, if used, is attached to a haulback line. Jammer logging is limited to uphill yarding of clear cuts and distances of 300-400 feet. Consequently, an intense network of roads, oriented predominately parallel to the contour, is required for this system. Logs are usually decked along the lower side of the road (Studier and Binkley 1974). The dense road system and constant contact of the log with the ground during skidding, required in jammer logging, creates considerable soil disturbance and erosion potential.



JAMMER GROUND SKIDDING
LOGS UPHILL

FIGURE 5

Skyline logging systems, the most versatile of all cable logging methods, were introduced in the Pacific Northwest in the early 1900's (Pearce and Stenzel 1972). Since the turn of the century, loggers have devised a number of skyline systems including the Tyler, North Bend, South Bend, and the Lidgerwood skidder. In the late 1940's and early 1950's, the European skyline crane systems were introduced in the Pacific Northwest primarily on an experimental basis (Wooldridge 1960). These systems are capable of yarding timber from the most difficult sites with almost no soil disturbance or damage to the residual stand. Electronic carriages for use on existing high lead and slackline yarders were developed in the late 1950's in response to a need for a highly productive system which included also the silvicultural advantages of the European skyline cranes (Lysons 1973).

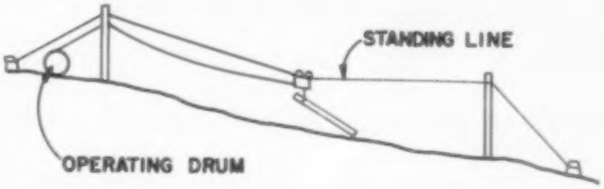
Binkley (1966) describes the skyline crane as a yarding system incorporating a carriage which moves logs laterally and then longitudinally along a suspended cable. Logs are first yarded to the skyline with one end on the ground. Subsequently, the logs are moved longitudinally along the skyline either completely suspended free of the ground or with one end on the ground, depending on topography and type of equipment used. For downhill yarding it is preferable to suspend the logs free of the ground. Uphill yarding can be accomplished with one end of the logs in contact with the ground while still keeping soil disturbance to a minimum.

Lysons and Twito (1973) have categorized all skyline systems as one of three types:

1) tight skylines (single or multispan)
2) slack skylines (also called live skylines)
3) running skylines

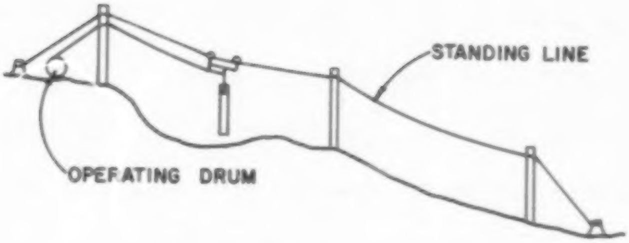
Differences between the systems primarily involve the skyline set up, type of carriage and yarder design.

The tight (standing) skyline has both ends anchored and employs either a single or double drum yarder for moving a carriage along the skyline (Figure 6). Most tight (standing) systems can yard either uphill or downhill; however, downhill operation is more common. Depending on the type of yarder used, yarding distances up to 5,000 feet are possible (Studier and Binkley 1974). For full suspension of the logs during longitudinal yarding, multispan rigging is sometimes necessary (Figure 7). The long yarding distances allow a low road density.



TIGHT SKYLINE
(SINGLE SPAN)

FIGURE 6



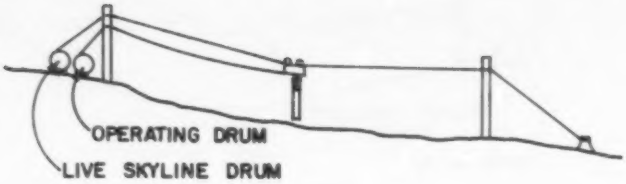
TIGHT SKYLINE
(MULTISPAN)

FIGURE 7

European skyline cranes are essentially multispan tight skyline systems designed primarily for downslope yarding and can be used for either clear cuts or partial cuts. The Wyssen Skyline crane was introduced in North America in the late 1940's. The system can be categorized as a standing skyline which combines both lateral and longitudinal yarding capability. Single span and multispan arrangements are possible. The system is capable of lateral skidding distances of up to 250 feet and longitudinal yarding of up to 5,000 feet. Logs can be yarded either partially or completely suspended above the ground. The multispan system is designed for complete suspension of the logs, except during initial lateral skidding.

The multispan system's skyline (Figure 7) permits long skyline roads using intermediate support which allows large areas to be yarded with minimal site disturbance. Soil disturbance which does occur is limited largely to short distances along the contour. Consequently, erosion problems are reduced to a minimum. Yarding can be upslope or downslope, reportedly over distances up to 6,000 feet. One of the major advantages of the skyline crane system is the unusually large yarding distance and concomitant minimal road density.

The slack skylines, also known as live skylines, require at least two drums on the yarder. One end of the skyline is anchored and the opposite end is attached to a drum on the yarder so that the skyline can be lowered to attach to a load (Figure 8). Carriages are operated mechanically by radio control. Either chokers or a grapple is used for attachments of the logs.

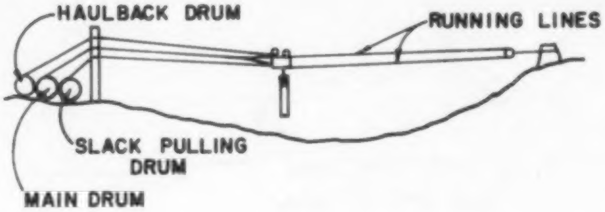


SLACK SKYLINE

FIGURE 8

These systems are reportedly more versatile and productive than standing skylines (Lysons and Twito 1973). Except during lateral yarding, the logs are mostly free of the ground, thereby allowing faster inhaul while minimizing soil disturbance and damage to any residual trees. Maximum yarding distances are approximately 2,000 feet. The systems can be used for partial cuts as well as clear cuts.

One of the latest innovations in cable logging systems is the running skyline (Figure 9). Running skyline systems require the use of interlock mechanisms that couple the main and haulback drum to control line tension and resulting lift forces. Uphill and downhill yarding over distances of up to 2,000 feet are possible. The use of a slack-pulling carriage permits lateral yarding for distances of up to 150 feet (Burke 1975; Lysons 1973). During lateral yarding, one end of the log is in contact with the ground. With adequate deflection, however, longitudinal yarding is accomplished with the log free of the ground. When equipped with a slack-pulling carriage both partial cuts and clear cuts can be yarded. Grapple yarders, however, are limited to yarding of clear cuts.



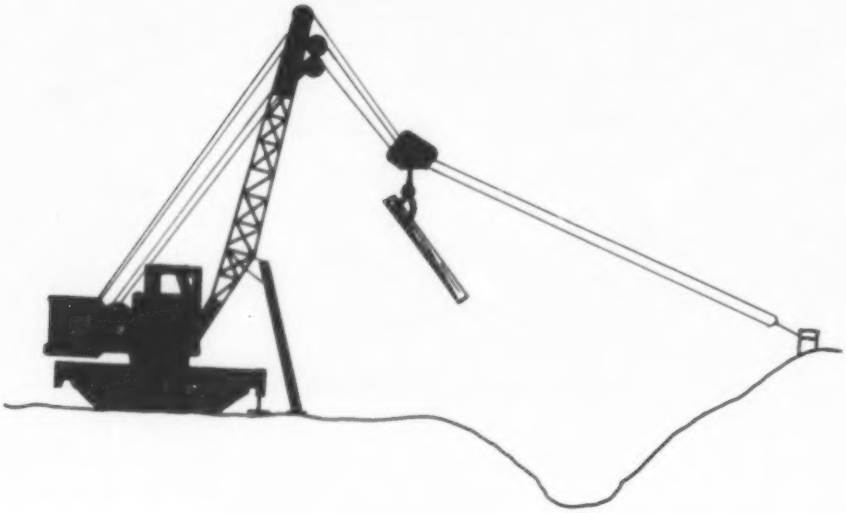
RUNNING SKYLINE

FIGURE 9

A mobile crane equipped with a running skyline and either chokers or a grapple is a highly efficient and adaptable yarding machine (Burke 1972) (Figure 10). Logs can be yarded for distances to 1,000 feet. The system can be moved with minimal losses of time. Logs can be lifted clear of the ground, minimizing soil disturbance. Both uphill or downhill logging can be accomplished. Since the crane moves along a truck road, a near parallel network of yarding roads is required. Logs are distributed along the edge of the road rather than being concentrated at a landing. As a result, this type of logging system has considerable potential for reducing site damage.

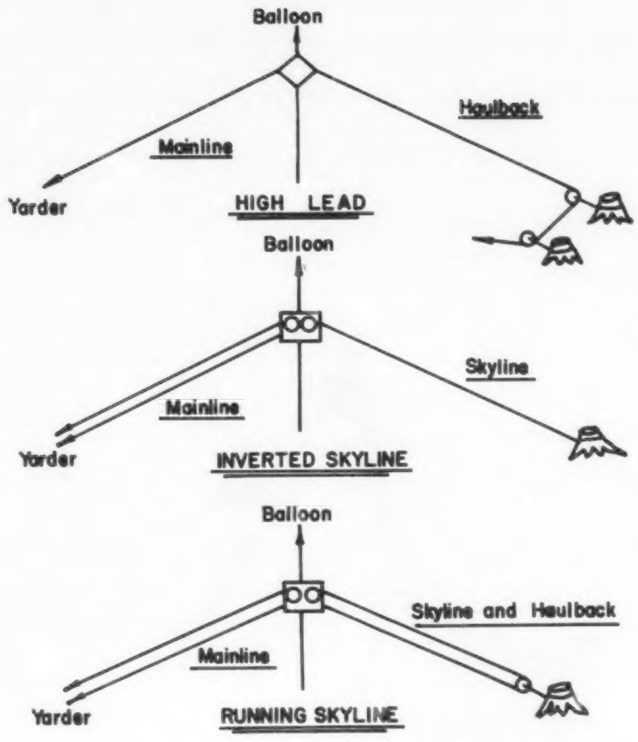
Balloon yarding was tested in northern Europe during the 1950's, and in Canada and the United States in the 1960's. Helium-filled balloons of a variety of types and sizes are used to lift the logs. Three rigging systems have been used for balloon logging: high lead, inverted skyline and running skyline (Peters 1973) (Figure 11). A tail block and a series of corner blocks are required in order to bring the balloon close to the surface for attaching the logs. The blocks are moved as needed to bring the balloon down to the ground at various locations (Figure 12).

Theoretically, a maximum yarding distance of 5,000 feet is possible; however, 2,500 to 3,000 feet seem to be a more realistic limit (Peters 1973; Gardner _et al_ 1973). Each turn of logs can be lifted entirely free of the ground surface. Hence, the system is particularly adaptable to logging steep slopes with fragile soils which are highly susceptible to erosion. Damage to residual trees can be kept to a minimum. However, balloon logging is particularly vulnerable to adverse weather conditions.



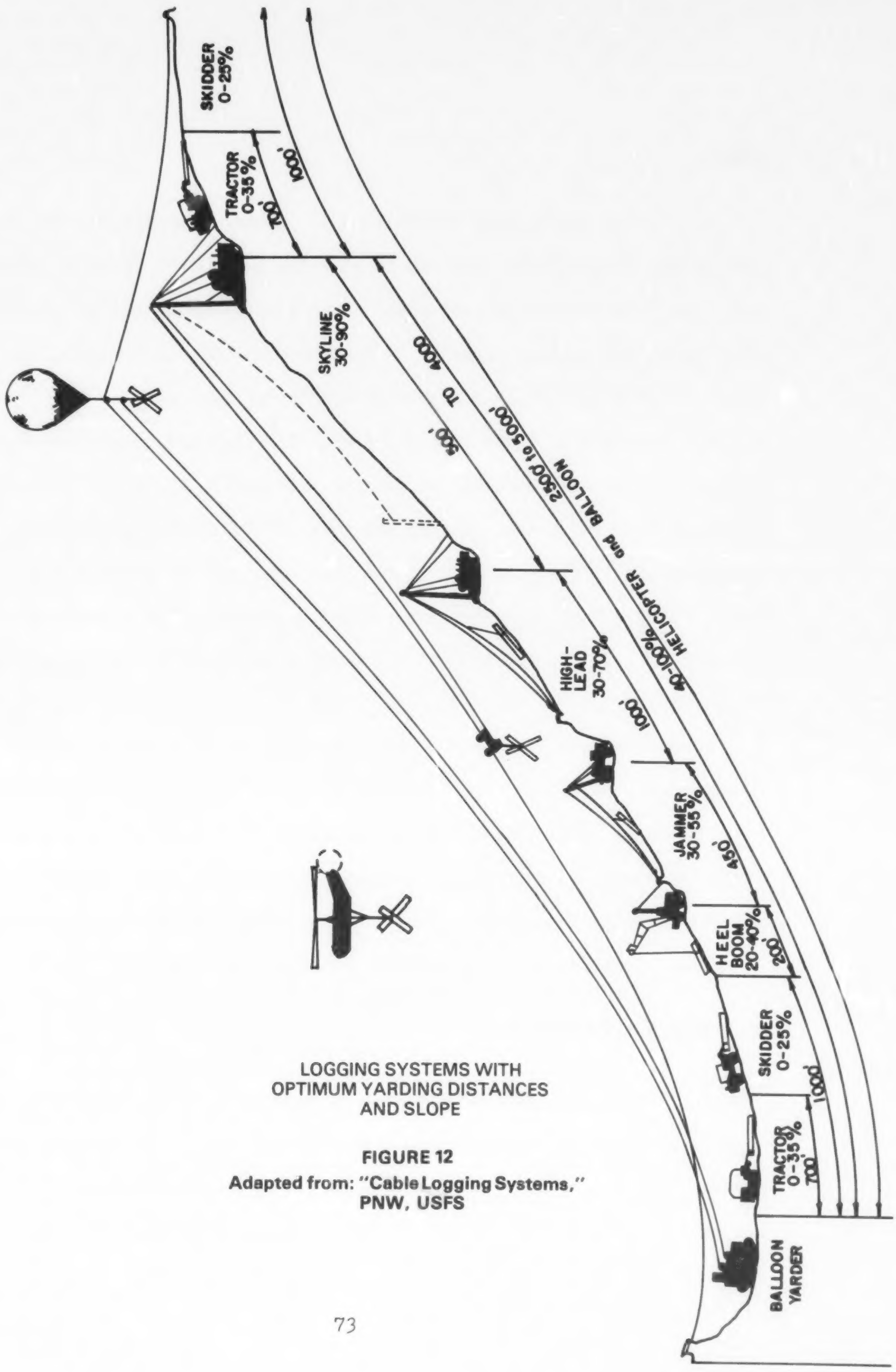
**MOBILE-CRANE
GRAPPLE-YARDING SYSTEM**

FIGURE 10


Balloon
Haulback
Mainline
Yarder
HIGH LEAD
Balloon
Skyline
Mainline
Yarder
INVERTED SKYLINE
Balloon
Skyline and Haulback
Mainline
Yarder
RUNNING SKYLINE

BALLOON LOGGING
RIGGING SYSTEMS

FIGURE 11


BALLOON YARDER
TRACTOR 0-35%
700'
SKIDDER 0-25%
1000'
HEEL BOOM 20-40%
200'
JAMMER 30-55%
450'
HIGH-LEAD 30-70%
1000'
HELICOPTER and BALLOON 40-100%
2500' to 5000'
300' TO 4000'
SKYLINE 30-90%
TRACTOR 0-35%
700'
1000'
SKIDDER 0-25%

LOGGING SYSTEMS WITH
OPTIMUM YARDING DISTANCES
AND SLOPE

FIGURE 12
Adapted from: "Cable Logging Systems," PNW, USFS

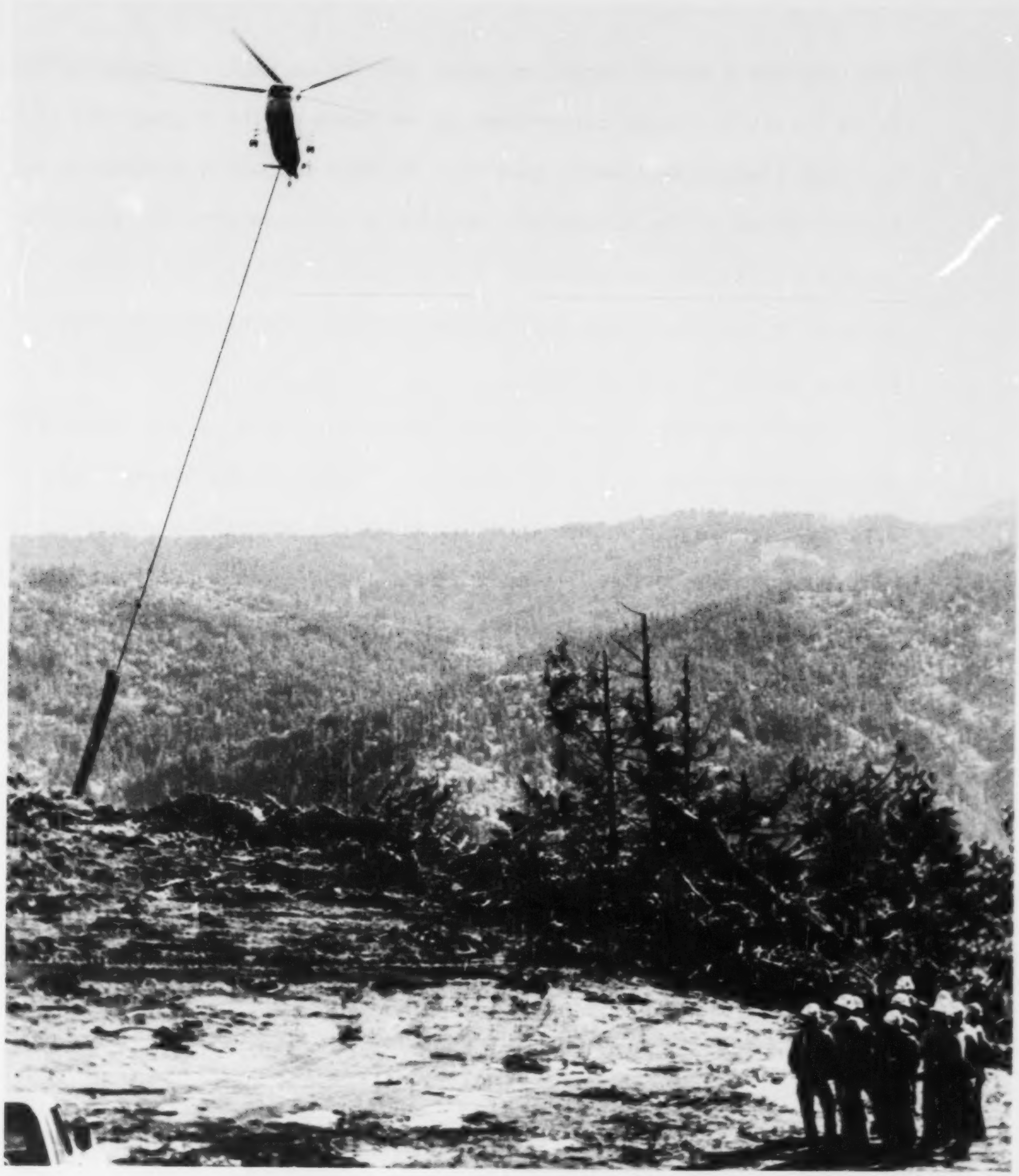
AERIAL

One of the more recent innovations in yarding involves the use of helicopters (Figure 13). One way to view the helicopter is as an expensive, infinitely-mobile yarder which can elimate many of the constraints that hamper conventional logging systems in areas of environmental concern. Yarding distances in excess of 6,000 feet are possible with optimal distances of 2,500 to 4,000 feet. The logs are flown completely free of the ground from stump to landing. Consequently, soil disturbance can be held to a minimum. Safety and maneuverability requirements necessitate the construction of large landings, perhaps as much as one acre in size. Most operators prefer uphill yarding. For a yarding distance of 2,500 to 3,000 feet an elevation gain of 800 feet is reasonable (Burke 1973).

Because of the high cost of equipment and large crews necessary, hourly operating costs of helicopters can be 10 times that of conventional cable systems. Helicopters are limited by their vulnerability to weather, limits to elevation differences between stump and landing, and lack of suitable landing locations. Lack of access roads can hamper post-harvest management (residue and regeneration) of logged area (Burke 1973).

WATER QUALITY IMPLICATIONS

The impact of logging activities on water quality is determined largely by the extent to which a forested area is disturbed by the network of access roads and by the movement of logs from stump to landing. Soil compaction brought about by the use of heavy equipment such as logging



HELICOPTER LOGGING AT A LANDING IN
THE BOISE NATIONAL FOREST, IDAHO

FIGURE 13

tractors has a direct impact on water quality as well. Logging methods which result in higher concentrations of slash on the logged area can also adversely affect water quality. Because Chapter 4 includes a detailed review of the literature pertaining to these effects, specific literature will not be cited in this section. Rather, this brief summary is concerned with contrasting various logging systems insofar as they can affect water quality.

Helicopter and balloon logging generally result in the least amount of soil disturbance at the felling site. Helicopters, however, are expensive and require large landings which can contribute measurably to soil erosion if not properly maintained. Both systems are vulnerable to adverse weather conditions; their use can therefore extend the time required to complete logging of an area, and consequently, the period of erosion susceptibility may be extended. On the other hand, the required road density is at a minimum, which is of considerable value in reducing erosion potential.

Long reach single or multispan skyline systems with capability for lateral yarding and complete suspension of logs during longitudinal yarding also allow low road densities for access. Disturbance of the felling site is restricted almost entirely to that which occurs during lateral yarding. Normally this disturbance is minimal. Landings of moderate size are required. Depending on the system used, the rigging time can be longer than that required for more portable skyline systems. Consequently, the time required to complete logging can be extended. Nevertheless, of the various cable systems, this type will in general have the least impact on the site.

Since the maximum yarding distance of slackline systems is in general less than that of the tight skylines, road density must increase with their use. The degree of site disturbance, exclusive of the road system, brought about by slackline systems is comparable to that of tight skylines. Rigging time is comparable, also. Since the slackline systems are in general more productive than tightline systems, the total time required to log an area is reduced over that of most tightline systems. When considering all factors, tightline and slackline systems probably inflict comparable levels of overall site disturbance.

The maximum yarding distance of running skylines is comparable to that of slackline systems. Consequently, road density could be expected to be comparable, also. Frequently, a crawler tractor is used for the tail hold of a running skyline. Movement of the tractor over the setting can introduce additional soil disturbance and compaction. Normally, however, the magnitude of this additional disturbance is minimal. Rigging time is low and production rates of running skylines are in general higher than other cable systems. Consequently, for a given setting logging can be completed in a relatively short period. When equipped with running skylines and a grapple, mobile cranes can yard logs to continuous landings adjacent to the road (Burke 1972). Consequently, site disturbance due to land construction can be limited.

High lead systems, which are suitable for uphill logging of clear cuts only, are restricted to yarding distance of 1,000 feet, although 700-800 feet is probably a more reasonable maximum. As a consequence, access road mileage must be increased for use of this type of cable system over that of the cable systems discussed earlier. More importantly, however, high lead systems provide practically no lift to the logs during yarding except in close proximity to the yarder. In general, the area of soil disturbance is increased over that of the various skyline systems. Also, smaller settings of high lead logged areas require a higher concentration of landings as compared to skyline systems. Since, for the most part, logs are skidded while in contact with the ground, high lead systems tend to concentrate slash in ravines and stream bottoms. These concentrations can have adverse impacts on water quality due to floatable debris in streams and the development of debris dams.

Jammer logging is the most road intensive of all of the cable systems. Restricted primarily to yarding uphill, jammers provide little or no lift to logs during skidding. Consequently, relatively large areas of soil disturbance usually result. Normally the logs are decked below the road for loading and hauling, so the area of soil disturbance for landings is relatively small.

Tractor logging with either wheel skidders or the crawler variety can disturb soil over relatively large areas. The compaction that results from tractor logging reduces infiltration rates and accelerates surface erosion. Soil disturbance and surface erosion are increased when tractors are used on steep terrain at higher elevations. In general, tractor logging should be limited to slopes of less than 35 percent. Because tractors generally operate most efficiently over relatively short skidding distances, access road mileage can be expected to be high and similar to that of high lead logging. Studies have shown that if logging is well planned in advance, site damage during tractor logging can be markedly reduced over that of an unplanned logging operation.

Forest Residues

MANAGEMENT

Forest residue is defined as the unwanted, generally unutilized accumulation in the forest of woody material, including litter on the forest floor, that originates from natural processes or from the activities of man, such as timber harvesting, land clearing and cultural practices (Jemison and Lowden 1974). Harvesting operations produce large quantities of residue, but so do many other forest operations. Small trees, tree limbs, and tops are left as residue following precommercial thinning. Land clearing of all kinds, e.g., roads, utility right-of-way, and for urban and agricultural development, is responsible for the production of sizable volumes of residue.

The conversion of brush lands to sawtimber and the conversion of one timber type such as alder to a softwood, a frequent occurrence on the west slope of the Cascade Range, will frequently produce large volumes of residue. Residues are produced when trees or other vegetation are killed by natural processes such as insect kills, wind, disease, fire and drought. However, it is the residue from logging that is of major concern because of the large volumes produced and the vast area covered (Jemison and Lowden 1974). Many of the most damaging fires in the Pacific Northwest start or spread in slash, particularly on the west slope of the Cascades (Howard 1971).

In the Douglas-fir region of Western Oregon and Washington, gross volume of slash ranged from 1,507 cubic feet per acre on private lands to 4,511 cubic feet per acre on national forest land. Logging slash in the ponderosa pine regions is substantially less. Gross volumes ranged from 423 on private lands to 404 cubic feet per acre in national forests. Net volumes were slightly less at 376 and 325 cubic feet per acre, respectively.

The larger volumes of residue on national forest lands can be attributed to a higher proportion of old-growth timber (which produces more slash) and the fact that private companies operating on their own lands receive all benefits from residue reduction efforts such as increased mobility for second growth management (Howard 1973). The differences in volume suggest that management of residues in the Douglas-fir region will be more complex than that required for the ponderosa pine region.

Typically, residue management techniques fall into four broad categories (Jemison and Lowden 1974).

1) no treatment
2) rearranging or mechanically treated and left
3) removal and disposal
4) burning

Each year slash on a large part of the forests in the Pacific Northwest receives no treatment. Areas in which the volume of slash is relatively low often requires no treatment, and leaving slash untreated may in some instances be the least destructive practice. Where needed, for example, residues can benefit soil formation processes and reduce soil erosion. Notwithstanding, the fire hazard posed by untreated residues can be intolerable, particularly on the west slope of the Cascades where residue volumes tend to be large. Intense fire exposes the soil surface and can lead to accelerated erosion.

The practice of rearranging or mechanically treating residue, practiced in some parts of the country with success, has received only limited use in the Pacific Northwest. During the past ten years heavy equipment for chopping, crushing or masticating residues has been developed. Generally speaking, the equipment is suitable only for areas in which residue sizes and total volumes are relatively low. Most of this equipment must be used in conjunction with a crawler tractor and hence is limited to slopes of 35 percent or less. Soil compaction can result. Chipping of residues for dispersal over roads, landings and cutover areas has been suggested. However, chipping is costly. In areas of high volume slash, chips can reach an excessive depth and thereby add to the fire hazard, reduce the availability of soil nitrogen and impede regeneration. On the other hand, chips protect the soil from high impact rainfall and can reduce soil losses due to surface erosion.

Beginning in about 1970 the U. S. Forest Service initiated a practice of yarding the larger size classes of residues from recently logged units. The practice, termed YUM (Yarding Unmerchantable Material), was limited to a relatively small proportion of the cutover areas located predominately on the west slope of the Cascades. Unmerchantable material is yarded during or following log removal and piled at the landing. In some instances, especially designed cable logging systems are used to yard residues. Later, the material is burned, or if a substantial volume of the material is sound and market conditions are favorable, it may be sold on the pulp market.

Burning of residues is practiced in all parts of the Pacific Northwest. The extent to which burning is used on both public and private lands is governed primarily by factors such as the state of advanced reproduction, cost of burning, size of the fuel load, and the availability of favorable burning conditions.

Area slash burning, piling and burning, and light underburning are by far the most commonly used control methods. These burning techniques have been used extensively for a number of years. More recently the use of incinerators, sometimes referred to as bin burners, has been introduced for disposal of residue in heavy use areas such as campgrounds, ski areas, along roads and near developments. Incinerators can be of simple design such as especially prepared open pits. Alternatively, portable prefabricated steel bins are available. Bin burners have, to date, received only limited use for residue management primarily due to high cost.

Slash burning is usually done in the spring or fall, although summer burning is sometimes practiced along the coast. Fire lines are built either by hand or with bulldozers around the area to be burned. Snags are felled to lessen danger of fire escape and prelocated pumps, hose systems, tankers, and standby fire crews may be used.

Area slash burning, more frequently called broadcast burning, has been the most widely used of all burning techniques. According to Jemison and Lowden (1974), in the 1962-64 period clearcut logging slash on all ownerships in Oregon and Washington was broadcast burned on 51,800 ha. and piled and burned on 50,991 ha. Since that time, broadcast burning has decreased 40 percent and pile and burn acreage has increased 50 percent, due in part to a change from clearcutting to partial cutting on national forests. Although used primarily on the west side of the Cascade Range in clear cuts, broadcast burning is used occasionally in the pine areas east of the Cascades where residue volumes are low.

As suggested earlier, piling and burning is usually associated with some form of partial cutting, e.g. selection cutting. Piling before burning affords a measure of protection to the remaining stand. Depending on the quality, size, and dispersal of residue, either machine or hand piling is used. Machine piling is more common and the slash is bunched in piles or is windrowed. Crawler tractors are equipped with special brush blades with teeth in order to minimize the quantity of soil that is deposited in the slash piles. Other types of piling equipment have been used but the tractor receives widest use. Windrowing of slash is practiced on the west slope of the Cascade Range as a part of the scarification of lands prior to artificial regeneration. Light underburning of uncut forest is a practice confined largely to the southern states. This particular control method has been suggested for ponderosa pine but to date has received limited use.

WATER QUALITY IMPLICATIONS

Residue management techniques influence surface erosion, mass soil movement, and the quantity of both dissolved and undissolved organic materials which are present in runoff waters. In general, any treatment such as residue management which removes or disturbs organic matter in contact with the soil surface may increase soil erosion and stream sedimentation (Rothacher and Lopushinsky 1974). Leachates from residues, if present in sufficient quantity, can collect in streams following logging and can be toxic to aquatic organisms.

Rothacher and Lopushinsky (1974) point out that from the standpoint of surface erosion it may be best to leave slash after logging without further disturbing the site (no treatment). However, Haupt and Kidd (1965) have shown that slash can be rearranged to form skid trail barriers and retard surface erosion. Slash can be relocated on hillsides and in stream bottoms to act as a sediment filter or trap. Also, cull logs placed across the slope can be beneficial for trapping material moved by surface erosion.

Chipped residues distributed over landings and along right-of-ways can also be beneficial for reducing surface erosion. On the other hand, mechanical treatments such as crushing and chopping of residues requires the movement of tractors equipped with auxiliary devices over the cutover area. Fire lines constructed with crawler tractors also require the movement of heavy equipment on cutover lands. Practices of this type can accelerate surface erosion due to exposure of additional mineral soil, compaction, and reduced infiltration.

Normally, the additional soil disturbance brought about by yarding unmerchantable material (YUM) should not add substantially to problems of surface erosion unless the logged area is unusually steep. Not infrequently, residues located on steep hillsides near the head of a drainage tend to collect in the stream bottom. Yarding residues can help avoid this particular impact to water quality. On the other hand, as pointed out by Brown (1974) the practice of burning all residue yarded to a central point located in a draw near the landing can create a severe source of erosion. Burying of residues introduces an additional area of soil disturbance.

Although, as Rothacher and Lopushinsky (1974) point out, residue treatments apparently have little direct effect on mass soil movement, their indirect contribution can be marked.

> Residues may indirectly contribute to mass erosion. For example, in steep terrain, logging slash may be moved downslope by small slides of saturated soil to block stream channels. This, in turn, can result in large debris-mud torrents causing severe mass erosion. Any logging debris left in stream channels will increase the chance of channel blockage.

A number of studies reviewed in Chapter 4 indicate that infiltration rates are reduced and surface erosion accelerated in soils which are severely burned during slash fires. Considerable quantities of organic matter, an important cementing agent in soil aggregate formation which effects infiltration rate, can be lost from the soil, especially under conditions of elevated temperature. Although the area of severely-burned soil is normally relatively small (5-8 percent), it is increased by broadcast burning in areas of heavy concentration of slash. Piling and burning of unmerchantable material can also result in severe burns in localized regions.

Burning can markedly increase the release of chemicals, some of which reach streams and influence water quality (Frederickson 1971).

Tiedemann (1973) has reported that fire was responsible for increasing nitrate-N concentrations in runoff waters from experimental watersheds. Concentrations of calcium, magnesium, and sodium declined, presumably due to dilution caused by increased runoff.

Log Storage and Handling

PRACTICES

Approximately 3 billion board feet of logs are dumped and handled each year in the public waters of the Pacific Northwest (Hansen _et al_ 1971). Of this total, a relatively small quantity of logs is processed in stream and impoundments in Idaho and Montana, and approximately 500 million board feet are dumped in the coastal waters of southeast Alaska (Pease 1974). The remainder, a quantity in excess of 2 billion board feet, is dumped in the waters of Washington and Oregon.

Log storage in the free flowing rivers as well as freshwater impoundments in the inland part of the Pacific Northwest is relatively small. In contrast, log storage west of the Cascades is predominately in salt water bays and estuaries or near the mouths of the larger river systems. It is reported that 650 acres are required for log storage in Alaska (Pease 1974). This figure suggests that the log storage area in the coastal region of Washington and Oregon may be approximately 2,500 acres.

In Alaska the composition of log rafts is approximately 70 percent western hemlock, 25 percent sitka spruce, and 5 percent western red and yellow cedar. In the inland part of the Pacific Northwest western white pine, ponderosa pine and Douglas-fir are the principal species that receive water storage, whereas, the bulk of the logs stored in western Washington and Oregon are Douglas-fir and western hemlock.

In northern Idaho limited log storage facilities have been developed on the St. Joe River, on the Clearwater and Palouse River and on the Pend Oreille River near Newport, Washington. For the most part the logs are free-fall dumped from trucks at specific sites. Several of the facilities are used for holding logs prior to processing in nearby sawmills and/or pulp mills.

Pease (1974) has identified four types of log storage facilities in the coastal waters of southeast Alaska.

1) sale area dumping sites
2) sale area raft collecting and storage sites
3) winter raft storage sites
4) mill storage and sorting sites.

Several methods for introducing logs into the water have been identified, including:

1) bundled on land, lifted and lowered into the water using a crane
2) bundled on land and either slid or skidded into the water
3) lifted, skidded or slid into the water individually and then bundled
4) dumped on the beach, bundled, and skidded into the water at high tide

After dumping, logs are collected into rafts approximately 70 x 550 feet in dimension, each of which can contain in the range of 300-600 thousand board feet. Bundled logs stored in the salt water bays of southeast Alaska sometimes run aground particularly at low tide. Pease (1974) reports that the abundance of benthic infauna was reduced drastically at a log storage area in southeast Alaska due to the grounding of bundled logs. Bottom sediments had been compacted to the consistency of sandstone.

In western Oregon logs are dumped in a number of salt water bays and estuaries including Coos Bay, Yaquina Bay and Siuslaw Bay, Tillamook Bay and Youngs Bay. In addition, logs are stored in the waters of the lower Willamette River and in the sloughs of the lower Columbia. Other freshwater storage areas include the Klamath and Deschutes Rivers. Logs are introduced in the water by free-fall dumping and the lowering of bundled logs with a crane. In some locations, logs are stored in the water for varying periods of time prior to processing. In other regions, large rafts are made up of bundled logs for transport by tug to a mill site. Raft sizes are similar to those used in Alaska.

In western Washington, most of the log storage facilities have been developed in Puget Sound and the Straits of Juan de Fuca. Grays Harbor and Willipa Bay and the lower Columbia River also serve as major locations of log storage facilities. Rafting operations are maintained at several locations on the south end of Puget Sound, including Budd Inlet, Henderson Inlet, and Oakland Bay near Shelton. A relatively small rafting operation exists in Hood Canal. In addition, the harbors at Tacoma, Seattle, Everett, Anacortes, Port Gamble, and Port Townsend are used for storage of log rafts. Log rafts are made up at the south end of Lake Washington and moved by tug through the ship canal into Puget Sound. In both western Washington and Oregon the species compostion of log rafts is approximately 70-75 percent Douglas-fir. The bulk of the remainder is in western hemlock. A relatively small part of the total is made up of western red cedar.

The development of heavy equipment suitable for efficient handling and sorting of logs has resulted in more extensive use of land storage facilities in recent years. Areas devoted to this purpose are frequently used for both sorting and storage and may or may not be used for supplying a processing facility located close by. Many, but not all, of the land-based sorting areas are equipped with sprinkling systems. Not infrequently, large quantities of bark and wood debris collects in the storage yards after long periods of use and must eventually be disposed of. Waters used for sprinkling usually are introduced into the natural drainage waters of the area. The extent of concentration of substances toxic to aquatic organisms which results depends largely on the number of logs in storage and on the size of the receiving stream system. In general, water-based storage facilities for logs are used much more extensively than land based operations in the Pacific Northwest. Consequently, insofar as water quality is concerned, it is the water-based facilities that have received and will continue to receive the most attention.

WATER QUALITY IMPLICATIONS

Pease (1974) and Schaumburg (1973) have identified two major wastes which affect water quality: (1) bark and wood debris, and (2) soluble organic materials (leachates).

Bark losses occur at several stages of log handling. The quantity deposited in water is governed primarily by:

1) species
2) method of handling
3) type of storage area
4) length of time in storage

The concentrations of leachates or water-soluble organic materials in storage water is determined by:

1) species
2) length of time in storage
3) flushing action of the storage area
4) the age of the logs at the time of timber harvest
5) the amount of bark remaining on the logs when in water storage

For specific information on the above, see Chapter 4.

CHAPTER 4
IMPACT OF FOREST PRACTICES ON WATER QUALITY

IMPACT OF FOREST PRACTICES ON WATER QUALITY

Surface Erosion

Surface erosion is the direct result of rain striking an exposed soil surface and detaching a soil particle, then transporting the detached particle by surface flow to some downslope deposition point. Forest practices disturb and expose mineral soil (as contrasted to the top organic layers) in varying degrees. In a review of literature concerning surface erosion, Smith and Wischmeier (1962) identified four basic physiographic factors affecting surface erosion:

1) rainfall characteristics
2) soil characteristics
3) topography
4) plant litter and cover

PHYSIOGRAPHY

Soil detachment is caused by raindrop impact and is therefore influenced by drop kinetic energy which varies with velocity and mass. The transport of detached soil particles in overland flow is controlled by runoff amount and turbulence, both of which are to some extent functions of rainfall intensity.

Soil properties pertinent to the erosion process include physical, chemical, organic, and saturation properties, parent material, and resistance to detachment.

Some of the earliest work on soil erodibility was conducted by

Middleton (1930). He developed two indices for indicating inherent soil erodibility: the "dispersion ratio" and the "erosion ratio." Both are based on laboratory determinations of aggregate stability, particle size distribution, and moisture content. Anderson (1951) tested Middleton's ratios for possible use in upland areas of California and recommended use of the dispersion ratio since he found it offered a somewhat better index of soil erodibility than did the erosion ratio. He supplemented these indices later with his "surface-aggregation ratio" (Anderson 1954). Wooldridge (1964, 1970) has used mean water-stable aggregate size as a measure of soil erosion hazard of forest soils. He reported a considerable decrease in mean aggregate size with increasing erodibility.

Parent material generally exerts a profound influence on the properties of forested upland soils. Profiles tend to be shallow and immature, and many characteristics may be inherited directly from the parent material. Willen (1965), Wallis and Willen (1963), and Andre and Anderson (1961) demonstrated that soils derived from acid igneous rocks tend to be considerably more erodible than soils derived from other parent materials. As a result of a study of soils at 258 locations, Wallis and Willen ranked 12 parent materials in the following manner:

Erodible parent materials--granite, quartz diorite, granodiorite, Cenozoic nonmarine sediments, schist.

Intermediate--diorite, a variety of metamorphic rocks.

Nonerodible--Cenozoic marine, basalt and gabbro, pre-Cenozoic marine sediments, peridotite and serpentinite, and andesite.

The size and shape of the particles or aggregates and the degree of soil compaction are the most important physical properties to be considered. Compaction generally retards particle detachment, but also reduces infiltration and thereby increases overland flow.

Organic matter is an important cementing agent in the formation of large water-stable aggregates. Wooldridge (1965) found organic content has a significant effect on surface erosion primarily through its effect on mean aggregate size. Willen (1965) also found that those soils which were the most stable had the highest organic matter content. Organic matter content is affected by vegetation, precipitation, and other climatic factors, consequently varying with aspect and elevation.

Ions adsorbed on the exchange complex in the soil may have a strong influence on erodibility by causing either flocculation or dispersion. Wallis and Stevan (1961) evaluated through regression analysis the effects of calicum, magnesium, potassium, and sodium on erosion, and found that calcium and magnesium had a positive and significant correlation with soil erodibility due to ionic dispersion and flocculation.

Saturation or water content of soils affects the buoyancy of the particles and the capillary forces, thereby influencing the resistance to detachment. Resistance to detachment also depends on cohesion (electrical bonding), adhesion (chemical and physical cementation), compaction, and the effective diameter-surface area relationships. Cohesion, adhesion, and compaction affect the internal forces holding the soil together. The effective diameter-surface area relationships affect the detachment force.

Hydrologic characteristics affecting the erosion process include the infiltration-runoff relationships, cover, runoff characteristics, soil-water interfacial characteristics and snowmelt. Infiltration-runoff relationships include percolation, or the surface water intake potential; permeability, or the potential groundwater flow rate; and the surface detention and storage capability of the land surface.

One of the most important factors involved in the erosion process is the amount of cover, which not only protects the soil surface from raindrop detachment but aids significantly in the interception, retention and infiltration process. Lowdermilk (1930) studied the effects of forest litter on runoff and erosion of several California soils. He concluded that the beneficial effects of litter cover were not due to its water absorbing capacity, but rather to its action in protecting soil from the destructive action of raindrops. Packer (1957) found that in the Boise Basin of Idaho, total ground cover and the maximum size of bare soil openings exerted the most influence on the erosion process, and concluded that in order to minimize runoff and erosion, ground cover density should be at least 70 percent, with maximum size of bare openings no greater than four inches.

Dortignac and Love (1961) studied vegetation and soil influences on infiltration in granitic soils of the ponderosa pine-bunch-grass type of the Colorado Front Range. They found the most important factors influencing infiltration were weight of dead organic material and the amount of non-capillary pores in the surface soil.

The primary elements related to the topographic effects on erosion include elevation, slope and aspect. Willen (1965) reported significant increase in erodibility (surface-aggregation ratio) with increasing elevation. Andre and Anderson (1961) have also observed a significant relationship between elevation and erodibility.

Bethalmy (1967) investigated the effect of exposure on runoff and erosion in central Idaho. He found that erosion was much more severe on southwest facing slopes, and concluded that this is primarily due to differences in the organic content of the soil.

SILVICULTURAL AND LOGGING SYSTEMS

The selection and layout of the silvicultural system directly affects the water pollution potential of the harvesting operation. Rothwell (1971) reported that the degree of site disturbance associated with cutting method decreases in the following order: clearcut, seed tree, shelterwood, group selection and selection.

The logging system used can have a major influence on the extent of soil erosion. In general, and not considering logging roads, the selection of the logging system most effects water quality. Effects range from severe to superficial, depending on the methods used, the degree of planning, and the attention paid to detail of plan execution. Roads for logging are a prime source of erosion and contribute directly to stream siltation (Packer and Christensen n.d.). Roads for skidding also contribute to soil erosion, but normally to a lesser extent than logging roads. Tractor and cable logging systems affect the land surface to different degrees of severity. The effects of tractor logging may be particularly severe in steep mountainous terrain.

Tractors cause deep soil disturbance in the form of compaction, displacement, or puddling under saturated conditions. This disturbance can be extensive because tractor yarding requires a network of skid roads over the entire cutting unit. Steinbrenner and Gessel (1956) showed that skid roads occupied [illegible]6 percent of the tractor logging area and that permeability rate on these skid roads was reduced 92 percent of that in the uncut area. Garrison and Rummell (1951) reported that in eastern Oregon and Washington, an average disturbance of 26 percent of the ground surface and the estimated density reduction of 33 percent in shrubby and herbaceous plant cover were results of tractor logging.

Cable systems, including high lead, skyline and balloon, have evolved into highly complex and efficient yarding methods. Because the cable is attached at some distance above ground, the high lead system provides a lifting force on the logs over a restricted part of the skidding distance. Consequently, less soil gouging results. Moreover, since the logs are generally pulled uphill toward the spar tree, the channels fan out, thereby tending to spread surface runoff. Some of the skyline systems permit yarding with very little ground contact at all.

Increasing environmental concerns have heightened interest in balloon and helicopter logging. Balloon logging requires few roads and eliminates much of the damage associated with logging because logs are lifted vertically from the ground.

The helicopter is essentially an infinitely mobile yarder which can eliminate many of the constraints that hamper conventional logging systems in areas of environmental concern. Helicopter logging may offer certain advantages where road access is restricted or use of conventional logging systems is prohibited, but it may have disadvantages related to cost, slash disposal, cull material handling, and post-harvest land management (Burke 1973). It is extremely sensitive to production cost. The most ideal use may be to remove scattered trees or pockets of high-value timber.

Of the various cable systems, jammer logging probably causes the greatest amount of soil disturbance. Yet, data are available to indicate that this system produces less damage than that brought about by tractor skidding. A study in Oregon and Washington by Garrison and Rummel (1951) showed that jammer logging is superior to tractor logging. Jammer logging on an area considered to be too steep for safe tractor operation produced deep soil disturbance over 2 percent (of the terrain) and exposed bare soil over 15 percent (of the area). By way of comparison, tractor skidding on more favorable terrain produced deep soil disturbance over 15 percent (of the area) and exposed bare soil over 21 percent. Campbell et al (1973) surveyed logging damage by rubber-tired skidders and reported that 23 percent of sites logged in Piedmont region were disturbed. McDonald (1969) showed that in a partial cut operation, forest soils were 12 and 22 percent compacted from wheeled and crawler skidders, respectively. Wooldridge (1960) also showed that in a partial cut of mixed conifer forest type in eastern Washington, tractor logging left exposed mineral soil on 22 percent of the area, whereas less than 6 percent was exposed by a skyline crane.

Haupt and Kidd (1965) reported that in central Idaho, soil was exposed by haul roads and skid trails on 8 percent of the total silviculturally-treated area, and that cutting by stem selection exposed about 1.4 times more mineral soil than cutting by group selection. They also found that a 10-foot minimum width stream buffer strip offered a fair margin of safety, but a wider minimum strip, perhaps 30 feet across, would have been more desirable. Lantz (1971), Hornbeck (1967), Hornbeck and Reinhart (1964), and Reinhart (1964) found that the maximum turbidities of streams was significantly increased on the watershed which was entirely clearcut. By way of contrast, no significant increases were apparent on the watersheds which were selection cut intensively.

Reinhart and Eschner (1962) investigated the effect of streamflow of four forest practices in the mountains of West Virginia. On a well-planned tractor logging operation the maximum turbidity was 25 JTU. An adjacent watershed was tractor logged without any plan or direction and maximum turbidities of 56,000 JTU were reported (Table 1).

Table 1. Effect on streamflow of four forest practices.
(After Reinhart and Eschner 1963)

Harvesting Method	Maximum Turbidity
Control watershed	15
Intensive selection	25
Extensive selection	210
Diameter limit	5200
Commercial clearcut	56000

These differences were attributed primarily to different skid road layout and construction.

The following tabulation (Table 2) taken from the results of Swanston and Dyrness (1973) illustrates variation in soil disturbance caused by four yarding methods used in clearcut operations in the Pacific Northwest (Dyrness 1965, 1967, 1972):

Table 2. Soil disturbance from four yarding methods and clearcutting. (After Swanston and Dyrness 1973)

	Percent bare soil	Percent compacted soil
Tractor	35.1	26.4
High lead	14.8	9.1
Skyline	12.1	3.4
Balloon	6.0	1.7

The literature suggests clearly that tractor logging is a poor choice for an area in which soil erodibility is a problem. In a study of balloon logging in central Idaho by Gardner, et al (1973), limited soil disturbance was noted. This method is well adapted to steep slopes (45 to 90 percent) and shallow and/or fragile soils. Balloon logging is generally limited to clearcutting with less usage for selection cutting.

Ruth (1967) stated that the silvicultural effects of skyline crane yarding were similar to conventional high lead yarding when measured in terms of soil disturbance and damage to tree seedlings and plant cover. The main advantage of the skyline crane system appears to be its effectiveness in yarding logs from steep slopes with minimum road construction.

Klock (1973) has reported on soil disturbance during logging and soil erosion after logging. His data showed that the percentages of the logged area observed to be eroded were cable skidding, 41 percent; tractor skidding on bare soil, 31 percent; tractor skidding on snow, 13 percent; and helicopter, 3 percent.

A determiniation of the sediment content of stream water flowing from experimental watersheds is one of the more common approaches to estimate erosion. One of the earlier studies of the effect of logging on stream sediment was conducted at the Coweeta Hydrologic Laboratory in North Carolina beginning in 1946 (Lieberman and Hoover 1948). No restrictions were placed on the operators and poor road construction practices were allowed. During logging, stream sediment content averaged 94 ppm with a maximum of 3500 ppm. Comparable figures for the unlogged control were 4 and 80 ppm, respectively. The increased sediment was traced largely to erosion from both the surface and backslope banks of logging roads.

Eroding skidroads were the major source of stream sediment in a logging experiment at Fernow Experimental Forest in West Virginia (Reinhart and Eschner 1962). Poorly located and constructed skid roads eroded to such an extent that maximum stream sediment contents reached 56,000 ppm (See Table 1). On the other hand, carefully planned and constructed skidroads contributed only negligible amounts of sediment. This study also showed that the impact on water quality was greatest during and immediately after logging and that recovery of vegetation substantially decreased erosion within one year.

Fredriksen (1970) indicated that following clearcutting and high lead yarding in three small western Oregon watersheds the sediment in streams averaged more than 100 times the undisturbed condition over a period of one year.

Megahan and Kidd (1972) used erosion plots and sediment dams to evaluate the effects of jammer and skyline logging systems on erosion and sedimentation of steep ephemeral drainages in the Batholith of central Idaho. The results indicated that no difference in erosion resulted from the two skidding systems per se. The logging operations alone, excluding roads, increased sediment production by a factor of about 0.6 over the natural sedimentation rate. Roads associated with the jammer logging operation increased sediment production an average of about 750 times over the natural rate for the six-year period following construction.

Trimble and Weitzman (1953) studied the erosional behavior of four different kinds of tractor skid trails on the Fernow Experimental Forest. High order skid trails having gradients of less than 10 percent and drained by waterbars as needed produced 55 lb/acre of sediment during the first year after logging. In contrast, erosion from poorly designed skid trails having no limit on gradients and no waterbars was 433 lb/acre, almost eight times as great.

Hoover (1954) reported that direct ground skidding of logs by teams, which is the common practice in the Southern Appalachian Mountains, was responsible for a loss of 4,370 ft^3/acre of road surface for a three-month period. Dils (1957) also showed that in the Coweeta hydrologic watershed logged by horse and oxen skidding, stream turbidities during a three-month summer period averaged 94 ppm, and maximum turbidity, consisting largely of mineral soils, was 3500 ppm. By way of comparison, stream turbidities on a control watershed averaged 10 ppm and the maximum turbidity, primarily organic material, was only 80 ppm.

Rice and Wallis (1962) showed that the suspended load of Castle Creek in a Sierra watershed was increased eight-fold during the first year after the beginning of logging, and the sediment load during the second year after logging was almost twice its normal rate.

Under average conditions, timber cutting per se, may have no measurable effect on erosion rates. Liken *et al* (1970), Dils (1957), and Lieberman and Hoover (1948) reported that if all vegetation is cut and left on the site, no increase, or negligible increase, in stream sedimentation will occur. Since log removal is concomitant with timber cutting this is not likely to occur in actual field operations, but it illustrates the relative water quality significance of cutting versus logging.

The effect of careful logging combined with clearcutting was investigated by Hornbeck (1968) on two watersheds. He concluded that small forested areas in steep terrain could be clearcut without serious erosion and damage to water quality if the logging operation was carefully planned and conducted. Brown and Krygier (1971) have reported that for a clearcut logging operation in the Oregon Coast Range, felling and yarding with a high lead system did not produce statistically significant changes in sediment concentration.

Lynch *et al* (1972) conducted a study in central Pennsylvania in which watersheds were partially clearcut and carefully logged with little disturbance to the soil surface. Regarding water turbidity, during the first year, the mean concentration was six times greater and the maximum was fourteen times greater on the clearcut than on the uncut forest. These differences in concentration became negligible during the subsequent four years.

Meehan et al (1969) studied the effects of clearcutting on streamflow, suspended sediment, stream temperature, log debris dams, and indirectly on salmon populations of two watersheds in southeast Alaska. Although some effects were observed, the timber harvesting as practiced on these watersheds did not appear harmful to salmon habitat or populations. James (1957) also found that logging did not change stream sedimentation and temperature in a logged salmon stream in Maybesco Creek, Alaska.

RESIDUE MANAGEMENT

The final step in the progression of timber harvesting involves the disposal of logging residues or slash which remains following removal of the merchantable logs. Effective forest management and the reduction of fire hazards dictate its removal. Fire is the tool most commonly used for this removal in many sections of the country.

Burning has been one of the more widely used methods for reduction of logging residues on clearcuts. Although severe burning may alter surface soil characteristics sufficiently to bring about some increase in erodibility, moderate and light burning often has very little direct effect on soil properties. Therefore, the most important changes caused by fire are often not in the mineral soil itself, but rather in the vegetation and litter which protect the soil surface. If essentially all surface fuel is consumed by an intense fire, exposure of mineral soil will result in decreased infiltration rates largely due to destruction of surface structure by raindrop impact. A light surface fire, on the other hand, will generally only char the litter, leaving most of the mineral soil at least partially covered. In many instances this remaining litter may afford sufficient protection to maintain soil porosity and, therefore, to avoid a large-scale increase in accelerated erosion (Dyrness 1967, Neal et al 1965, and Isaac and Hopkins 1937).

Results from Packer's (1971) research on logged and burned larch-Douglas-fir sites in Montana showed that the effects of prescribed burning on soil and vegetation can impair runoff and soil erosion control. Prescribed broadcast burning, in particular, on eight clearcut blocks significantly reduced the protective plant and litter cover, decreased the surface soil macroporosity, and increased the soil bulk density. Concurrently, overland flow and soil erosion produced both from snowmelt and from summer rainstorms increased measurably. However, this impairment of watershed protection conditions and attendant increases in runoff and erosion were only temporary; they had almost returned to the prelogging and preburning state within four years.

Dyrness (1967) measured the effect of logging operations and broadcast burning on disturbance to the soil and litter layer. The proportion of clearcut watershed burned, and the fraction of the burned area severely burned varied. The severity of the burn on these watersheds was moderate. Dyrness and Youngberg (1957) and Tarrant (1956), studying intensity of slash burning, found the severely burned area to range from less than 3 to approximately 8 percent of the total area burned.

Packer and Williams (1966) reported that burning drastically reduced the proportion of the ground surface protected by plants, litter and logging residue to less than 50 percent. Overland flow from the logged-burned areas was from two to several times greater than that from the unlogged-unburned ones. Soil erosion from the logged-burned plots averaged 56 lbs/acre for the first year after burning, but then increased to 168 lbs/acre in the second year. None of the unlogged-unburned plots produced any soil erosion from snowmelt flow during the subsequent years.

Brown and Krygier (1971) showed that after clearcutting and burning, sediment yields increased about five-fold, and maximum concentration increased from 970 to 7,600 ppm after burning. Fredriksen (1970) reported that for two years after clearcutting, skyline logging and slash burning, sediment concentrations were 67 and 28 times greater than those recorded on an undisturbed watershed during the same periods.

Ralston and Hatchell (1971) studied five watersheds in the southern United States and found that soil erosion was greater in the areas treated by prescribed burning, by factors ranging from 7 to 1,500 as compared to the unburned forests.

Although severe burning may reduce the percolation rate in the soil and increase surface runoff causing soil erosion, the overall influence on moisture properties of the soils was concluded to be minor (Tarrant 1956) since severe burns usually cover a very small portion of the total surface of a slash-burned area.

REFORESTATION PRACTICES

Reforestation efforts often require some type of site preparation prior to planting or seeding. The main types of site preparation involve the use of fire, chemicals and mechanical means. Mechanical methods of site preparation during the last ten years have included scarification, stripping and terracing (Packer 1971).

Packer (1971) showed that by creating depressions, machine scarification with debris spread in irregular patterns over the site usually increases the storage capacity of the land, but seldom increases the overland flow and soil erosion hazard. Avoiding excessive scarification will reduce the impact on the watershed (Rosgen 1973). Packer cautioned that in preparing sites that slope directly to stream channels, untreated ground should be left between strip sites and the stream as a buffer to water and soil movement. Packer also stated that little erosion has resulted from terracing since its first use in southern Idaho.

A U.S. Forest Service task force appraisal (1969-1970) on the Bitterroot National Forest found few signs of serious erosion on most of the terraced slopes but cautioned that long-run erosion could not be determined.

Immediate reforestation of the harvested area is usually desirable. After site preparation, planting is initiated. Hand planting or seeding, aerial seeding, or auger planting generally entail truck transportation. Machine planting requires tractors, which introduce some potential for further erosion if the planting is done a year or more after post-haresting stabilization.

Fredriksen (1970) showed the following tabulation (Table 3):

Table 3. Total understory vegetation cover and exposed mineral soil after clearcutting of timber and after burning of logging residue. (After Fredriksen 1970)

	Patch Cut Watershed			Clearcut Watershed		
Year Condition	Vegetation Cover Percent	Bare Ground Percent	Condition	Vegetation Cover Percent	Bare Ground Percent
1962 Undisturbed	70	3	Undisturbed	86	4
1963 Clearcut	10	16	Being harvested	-	-
1964 After burning	15	29	Being harvested	-	-
1965 Revegetating	49	28	Being harvested	-	-
1966 Revegetating	54	30	After logging	54	12
1967 Revegetating	80	27	Revegetating	76	54

Burning which followed completion of logging by several months reduced vegetation cover more on the patch cut than on the clearcut watershed. In the clearcut watershed, regrowth of fire resistant species during the three years required to complete logging may have been responsible for the large cover of vegetation the year following burning (1967). Revegetation was rapid in the case of both watersheds, but a sizable proportion of the soil surface remained bare of litter for several years following burning. On the patch cut watershed, the herb-rich vegetation established the first two years following burning gradually gave way to a rapidly expanding cover of shrubs and trees. By 1968, the total vegetation cover on the clearcuts in the patch cut watershed exceeded the cover measured in undisturbed forest in 1962.

A dense cover of vegetation and a nearly complete mat of forest floor material protects the surface soils from erosion in an undisturbed forest. Harvest operations and broadcast burning destroy a large part of the natural shrub and ground cover. Through reforestation this cover of vegetation can gradually be restored.

SUMMARY

Studies in the western United States indicate that the erodibility of forested upland soil is perhaps influenced most by characteristics of the parent rock. Soils derived from acid igneous rocks tend to be considerably more erodible than soils derived from other parent materials. The higher the quartz content of the parent material, the greater the potential erosion hazard of the resultant soil.

Other factors exerting considerable influence include nature of the vegetative cover, especially as it controls amount of organic matter in the soil, and climatic conditions as modified by elevation and aspect. In addition, soil chemical properties undoubtedly influence erodibility to an as yet unknown extent.

Site erosion potential should influence the selection of the silvicultural system. A suitable silvicultural approach may be anything from partial thinning to clearcutting and replanting. Although clearcutting may be suitable on stable sites, selection cutting may be necessary to provide the soil protection necessary in highly erodible areas.

The factors contributing most to increased soil erosion following logging are exposure of bare mineral soil and surface soil compaction from mechanical disturbance. Studies have generally indicated that clearcutting with tractor logging is the most destructive of all the logging systems (wheel skidding is also often severe) when considering compaction of soil. Skyline yarding, in all cases, is less severe than high lead yarding. Grapple yarding systems are intermediate between skyline and high lead or jammers, as they combine features of each. Balloon yarding is substantially less severe than skyline yarding. Helicopter yarding probably results in the least compaction because it transports logs free in the air over most of the logged areas.

Broadcast burning also can increase surface erosion, primarily through the removal of protective vegetation and litter. Sufficiently hot fires may also cause changes in surface soil properties. Perhaps the most serious of these are the breakdown of water-stable aggregates and lowering of organic matter content. The overall influence on moisture properties of the soils is minor since severe burns usually cover a very small portion of the total surface of a slash-burned area.

Mass Soil Movement

PHYSIOGRAPHY

Soil mass movements range widely in surface configuration, speed of movement and volume of material involved. Such movements may take the form of spectacular landslides and mud flows, or the more subtle, slower, downward creeping movement of an entire hillside. In terms of principal processes, however, dominant forms are classified by Swanston (1970, 1974) into three groups according to controlling features and principal movement mechanisms. These groups overlap geologic and physiographic boundaries and are controlled primarily by slope gradient, soil depth, soil water content and specific soil physical characteristics.

Debris Movements

Mass movements produced by instantaneous failure in shallow residual or alluvial soils overlying an impermeable surface is the group of most widespread occurrence. It includes debris slides, debris avalanches and debris flows. Movement may be triggered by surface loading, increased soil water levels, or a removal of mechanical support. Debris slides are the rapid downward movement of unsaturated, relatively unconsolidated soils and forest debris by sliding or rolling, and are differentiated from debris avalanches largely by soil water content. Debris flows involve the rapid downslope movement of water-saturated soil and debris by true flow processes. These types of mass movement are the dominant process in such diverse areas as the maritime coast of Alaska (Bishop and Stevan 1964; Swanston 1969, 1970) and the dryer intermountain areas of Utah, Idaho and Montana (Croft and Adam 1950).

Debris avalanches are also of frequent occurrence in southern California (Corbett and Rice 1966; Rice, Corbett, and Bailey 1969) during the rainy season, and Dyrness (1967) has observed them on the western flank of the Cascades following the Christmas storm of 1964. This group is strongly affected by timber harvesting activities. Road construction is the most damaging activity, largely through disruption of the natural balance of forces on the slope by cut and fill activities. Obstruction of slope drainage and local saturation of roadfills are also important initiators. Destruction of surface vegetation and deterioration of anchoring roots by land conversion and clearcut logging have also been linked with accelerated debris avalanche and debris flow occurrence (Swanston n.d.).

Creeps, Slumps and Earthflows

Another group of mass soil movements includes soil creep, slumping, and earthflows resulting from quasi-viscous flow and progressive failure of weathered pyroclastics, sandstones, and shales. In areas of extremely deep, cohesive soils, a combination of creep, progressive slumping, and earthflows may involve an entire watershed. In such areas, slumps and earthflows occur in zones of concentrated subsurface drainage. Slumping involves the downward and backward rotation of a soil block or group of blocks with small, lateral displacement. Earthflows frequently incorporate much larger masses of soil which move downslope through a combination of flows and slumping. Slumping and earthflows are common to most unstable areas of western North America but are especially important as an erosion process in the Northern Coast Ranges of California (Kojan 1967), where large volumes of sediment are being added annually to some streams by slumping and earthflow activity.

The direct affect of timber harvesting operations on this group has not yet been clearly identified. Road building is probably the most damaging activity. Road construction in active or dormant creep and slumping areas is likely to accelerate or reactivate the soil mass, largely through alteration of the balance of forces acting on the slope. Timber removal probably exerts an impact through alteration of the natural slope hydrology, producing unstable conditions during critical storm periods (Swanston n.d.).

Dry Ravel, Dry Creep and Sliding

The remaining group includes dry ravel or dry creep and sliding of coarse, cohesionless materials on steep, sparsely vegetated or recently denuded slopes. This is a common erosion process on unvegetated oversteepened slopes throughout the mountainous region of the western states, caused by loss of frictional resistance between individual soil particles due primarily to freeze and thaw and wetting and drying cycles. In areas characterized by steep slopes, coarse textured soils, and extended summer droughts it may be a particularly important process. It constitutes the dominant process of soil mass movement during the dry summer season in the San Gabriel Mountains of southern California (Krammes 1965). This type of movement involves the mechanical sliding or rolling of individual particles or aggregates under the direct influence of gravity.

Principal effects of timber harvesting activities on this group are removal of surface vegetation and construction of artificial embankments and road, exposing bare mineral soil to rapid weathering and cycles of freezing and thawing and wetting and drying.

SLOPE STABILITY

Two main variables should be considered in preparing a classification of mass movement (Varnes 1958): (1) the type of material involved, which usually is apparent on inspection or with preliminary borings and (2) the type of movement, which usually can be determined by a short period of observation or by the shape of the slide and arrangement of debris.

Varnes (1958) grouped the variables affecting slope stability into (1) those tending to reduce shear strength and (2) those increasing shear stress (Table 4). This method was used by Bishop and Stevens (1964) to examine factors causing landslides in southeast Alaska.

Factors Influencing Shear Strength

The initial composition and structure of parent material plays an important role in shear strength. Glacier-worn granite slopes frequently offer little support for soil or vegetation. Weak geologic structure, bedding structure, compacted glacial till in a wetted state and metamorphics are critical factors in some areas.

Fracturing and weathering characteristics of rock also may produce a weak foundation for the soil mantle. Some areas with diorite rock have weathered sufficiently to produce a thin mantle of small angular blocks overlying the unweathered surface. Soil filtering into these fissures gradually forces these blocks apart by freezing and thawing. This action, combined with gravity acting on steep slopes, produces a soil mantle weak in shear strength. Granites that disintegrate into

TABLE 4

FACTORS CONTRIBUTING TO INSTABILITY OF EARTH SLOPES

(After Varnes 1958) Taken from: Gray 1969

Factors that Contribute to High Shear Stress	Factors that Contribute to Low Shear Strength
A. Removal of Lateral Support 1. Erosion - bank cutting by streams and rivers 2. Human agencies - cuts, canals, pits, etc. B. Surcharge 1. Natural agencies - wt of snow, ice and rainwater 2. Human agencies - fills, buildings, etc. C. Transitory Earth Stresses - earthquakes D. Regional Tilting E. Removal of Underlying Support 1. Subaerial weathering - solutioning by groundwater 2. Subterranean erosion - piping 3. Human agencies - mining F. Lateral Pressures 1. Water in vertical cracks 2. Freezing water in cracks 3. Swelling 4. Root wedging	A. Initial State 1. Composition - inherently weak materials 2. Texture - loose soils, metastable grain structures 3. Gross structure - faults, jointing, bedding planes, varving, etc. B. Changes Due to Weathering and Other Physico-Chemical Reactions 1. Frost action and thermal expansion 2. Hydration of clay minerals 3. Drying and cracking 4. Leaching C. Changes in Intergranular Forces Due to Pore Water 1. Buoyancy in saturated state 2. Loss in capillary tension upon saturation 3. Seepage pressure of percolating groundwater D. Changes in Structure 1. Fissuring of preconsolidated clays due to release of lateral restraint 2. Grain structure collapse upon disturbance

soils that are high in sand content and low in shear strength occur on the mainland and parts of some islands in southeast Alaska (Bishop and Stevens 1964).

Varnes lists three ways in which pore water may reduce soil shear strength:

1) Buoyancy in the saturated state decreases effective intergranular pressure and friction.
2) Intergranular pressure due to capillary tension in moist soil is destroyed upon saturation.
3) Seepage pressures of percolating groundwater result from viscous drag between liquid and solid grains.

In cohesionless soils, significant pore pressures usually are not developed. A compacted cohesionless soil tends to increase in volume as it shears. Volume increase is opposed by a saturated but draining condition. Hence, a resistance to shear is developed. In contrast to cohesionless soils, cohesive soils consistently lose shear strength with addition of water, despite a complex and variable relationship to soil water.

Timber removed from a cohesionless soil will cause a reduction in shear strength in proportion to the change in weight because there is a change in the force normal to the slide plane.

Gradual deterioration of the root networks follows the timber harvest. The tenacious hold of root hairs and fine roots to soil particles is gradually lost. Loss of continuity in the network of tree roots near the soil surface may weaken the soil mantle. With a discontinuous root network on the slopes, strong anchor points that resist shear cannot absorb additional shear stress from weakened adjoining areas.

Factors Influencing Shear Stress

Glaciation is evident throughout some parts of the Pacific Northwest, in particular the Puget Sound Area, northern Idaho and Alaska. During the latest glacial period, glaciers carved steep U-shaped valleys. Erosion has not acted long enough to moderate the glacial slopes to more stable forms. Consequently, the soils on which many logging operations are conducted are derived from glacial deposits laid down on very steep or oversteepened slopes. Earthquakes, not uncommon in some parts of southeast Alaska, may trigger unstable slopes to move.

Faulting or uplifting can tilt the earth's surface, contributing to formation of oversteepened slopes. Faulting or uplifting may also steepen stream gradients. Tributary torrent streams may then produce and maintain oversteepened ravine slopes. Heavy rains develop shear stresses within the soil profile by adding the weight or driving force of water to the soil mantle and vegetation. The weight of vegetation is a significant part of the shearing force in the soil mantle.

Gray (1969) listed the possible ways vegetation might affect the slope stability as follows:

1) Mechanical reinforcement from the roots. Indirect evidence reported in the literature suggests that this may be the most important effect of trees on slope stability. Presumably deep-rooted species of trees or woody shrubs whose roots penetrate through the soil mantle to bedrock would enhance stability the most. Conversely, removal of such a vegetal cover with subsequent rotting and deterioration of the roots would have the most serious consequences.

2) Surcharges. At first glance this would appear to increase shear stress, but the effect is largely negated by a concomitant increase in shear strength due to the confining effect of the surcharge. Furthermore, Bishop and Stevens (1964) estimate that the surcharge due to the weight of the forest (spruce and hemlock) amounts to only 50 psi. This is equivalent to a layer of soil only six inches thick. Although the surcharge will have little effect on the calculated factor of safety, it will affect creep rates to some extent.

3) Wind throwing and root wedging. Strong winds blowing parallel to the slope will exert an overturning moment on the trees. This can lead to so-called wind throwing of trees which creates localized disturbances in the soil mantle. Wind throwing is a fairly common occurrence in some forests, but it normally affects only aged and diseased trees. The total down slope force created by a wind blowing through a forest and hence its overall effect on slope stability has never been evaluated. The effect of root wedging, an alleged tendency of roots to penetrate a soil, thereby loosening it up or opening cracks and fissures, likewise is presently unknown. Judging by evidence reported in the literature, particularly the observation by Bishop and Stevens (1964), the beneficial effects of root systems on slope stability far outweigh any possible adverse effects.

4) Modification of soil moisture distribution and pore pressure. Trees transpire water through their leaves and this in turn depletes soil moisture. Soil moisture depletion produces negative pore water pressure, which as seen previously is conducive to slope stability. A forest can also intercept moisture either in the crowns of trees or in the ground litter.

Gray developed three principal equations that can be used to determine the influence of a key variable, such as piezometric level on slope stability. These three equations concern, (1) factor of safety of the slope, (2) allowable height of piezometric level, and (3) the maximum rate of planar depth creep. Gray concluded that as the piezometric level approaches the surface of the soil layer, the creep rate accelerates markedly. Swanston (1967) also had good results in calculating the critical piezometric level in a drainage basin in southeast Alaska.

Dyrness (1967) showed the relationship between the occurrence of mass movement events and certain site characteristics in the H.J. Andrews Experimental Forest.

FOREST OPERATIONS

The primary effect of timber harvesting on the accelerating soil mass movements is a lessening of the mechanical support of the slope, chiefly by roadbuilding, logging and slash burning.

Roadbuilding has been identified as the greatest single cause of recent soil mass movements in the western states (Swanston and Dyrness 1973). This subject is explored extensively in a recent report by the EPA (1975) but a few points will be mentioned here. Road construction disrupts the basic equilbrium of steep slope forest soils through alteration of slope drainage, slope loading, and slope undercutting. The first includes interception and concentration of surface and subsurface flow by ditching, bend cutting and massive roadfills. This encourages saturation, active pore water pressure development and increased unit weight in road prisms, side-cast materials and soils upslope and downslope from the road cut. Poor drainage and plugged culverts can greatly magnify these problems by ponding water on the inside of the road. Slope loading by massive fill and side-casting greatly increases the weight of the soil material, resulting in increased gravitational stress along the slope below the road. Slope undercutting by benching along on oversteepened slope removes support for the upslope soil.

Cutting of trees alone does not greatly increase surface soil erosion as long as ground cover is maintained, however; on steep slopes cutting may cause debris accumulation and loss of the mechanical support from rooting structures of trees and other vegetation. Several investigations in the western states have linked increased occurrences of debris flows to logging after high-intensity storms.

The deterioration of stabilizing root systems seems to play an important part in this increased activity. Accumulation and flow of debris in steep ravines, both logged and unlogged, has also been cited as a major factor in mass soil movements (Swanston and Dyrness 1973).

Bishop and Stevens (1964) have shown a direct correlation between timber harvesting and accelerated soil mass movements in Alaska following heavy rains in the fall of 1961. More detailed work in this area by Swanston (1967, 1969, 1970) has shown that sections of almost every logged slope exceed that natural angle of stability of the soils (±34°). The majority of debris avalanches and flows developed on slopes greater than 34° and are especially frequent around a critical angle of 37°. Above this critical contour sliding is imminent, with the destruction or disruption of any cohesive forces acting to hold the soil in place. Below the critical contour is a zone of decreasing instability.

A study by Rothacher and Glazebrook (1968) found that in the national forest of Region 6 on highly erosive granodiorite soils, slopes over 40 percent cannot be clearcut without considerable soil loss from numerous slides.

Dyrness (1967) investigated accelerated soil mass movements on the west flank of the Cascade Range following heavy rains in the winter of

1964-65. He reported that out of 47 recorded debris avalanches, debris flows, earthflows and slumps, 72 percent were directly associated with roads and 17 percent with logging.

Kittredge (1948) observed that in the coast ranges near San Francisco many slides occur in wet years on the heavily grazed, grassland-covered clay soils, but that similar slides do not occur on the same soils in the eucalyptus plantations more than 25 years old. Gray (1969) concluded that there was a definite relationship between clearcutting and mass soil failures and pointed out that "there has been no rational attempt to predict what will be the factor of safety of a natural slope against sliding, before and after clearcutting."

Croft and Adams (1950) attributed increases in soil mass movement following high-intensity storms in the Wasatch Mountains to loss of mechanical support by root systems of trees and plants, chiefly by logging and burning. They concluded that before modern day land use landslides were rare and possibly absent from their study area.

Fire is an effective management tool in conjunction with logging slash and also to prepare the site for planting or seeding. It is an effective agent for accelerating dry creep and sliding and may indirectly influence soil mass movement on already unstable slopes. At its worst fire removes or destroys all protective vegetation. This can lead to mechanical unravelling of the slope and progressive deterioration of root systems. In southern California, as well as in the Wasatch Mountains of Utah, fire has been directly linked to massive increases in dry ravel or debris avalanching (Swanston and Dyrness 1973).

Krames (1960, 1965) reported that in October 1959, a wildfire swept through the Los Angeles River watershed and debris movement began almost immediately after the fire passed. Great quantities of debris moved downslope and into stream channels. The increase in the production of sediment by mass soil movement was from 10 to 16 times greater than normal.

Corbett and Rice (1966), and Rice, Corbett, and Bailey (1969) reported that soil slippage was increased by brush conversion from native chaparral vegetation to grass at the San Dimas Experimental Forest, California. The converted area contained about five to seven times as many soil slips as the control area.

SUMMARY

High soil-moisture content and steep slopes are common to most of the recent accelerated mass movements of soil on forest lands. Local bedrock type, climate and basic soil characteristics determine the individual failure mechanisms. External factors, including parent material structure and rooting structure of trees and understory vegetation, affect stability conditions on some sites.

The site characteristics which control mass soil movement include particle size distribution, angle of internal friction, soil moisture content and angle of slope. Shallow coarse-grained soils low in clay-size particles have little or no cohesion, and frictional resistance determines the strength of the soil mass.

Parent material structure is a critical factor in the stability of many shallow-soil slopes. Highly jointed bedrock slopes with principal joint planes parallel to the slope, and sedimentary rocks with bedding planes parallel to the slope, provide little mechanical support. They create avenues for concentrated subsurface flow and active pore water pressure development as well as ready-made zones of weakness and potential failure surfaces independent of the overlying material.

Vegetative cover in general helps control the amount of water reaching the soil and the amount held as stored water. Root systems of trees and other vegetation may also increase shear strength in unstable soils. This is particularly true when roots anchor through the soil mass into the parent material, and provide continuous long-fiber cohesive binders to the soil mass proper and across local zones of weakness within the soil mass. In some extremely steep shallow soils in the western United States, root anchoring may be the dominant factor in maintaining slope equilibrium of an otherwise unstable area.

The three major types of mass soil movements are:

1) Debris slides, debris avalanches and debris flows, produced by instantaneous failure in shallow soils overlying an impermeable surface. These soils are usually of coarse texture and low in clay content.
2) Creep, slumps and earthflows, resulting from quasiviscous flow and progressive failure of deeply weathered materials. Speed of movement ranges from a barely perceptible creep to high velocity slumps and earthflows.

3) Dry ravel, dry creep and sliding, involving downslope movement of single particles and thin sheets of coarse, cohesionless material on steep sparsely vegetated slopes.

Since roads are often an important factor in causing mass movement, the problem is to determine means of minimizing their effect. The most obvious means is to reduce road mileage to an absolute minimum. In steep, mountainous terrain, this may be done by the use of skyline and possibly balloon logging methods. In many areas, it is possible that improvements in road location may appreciably reduce the frequency of mass soil movement. Unstable soils and land forms should be identified, and the route selected should avoid these areas.

Channel Erosion

Stream sediment is generally assumed to be derived from two erosional processes: surface erosion and channel erosion. Mass soil movement is considered by some as a third form of erosion. The total sediment load for a stream is recognized to be composed of suspended material or wash load, usually derived from surface erosion, and bed load, primarily derived from channel erosion. The total amount of sediment in a stream depends on physical characteristics of the watershed and climatic variables.

The quantity of suspended material in a stream at any time primarily depends on the rate at which fine particles become available from the watershed. It is a function of such factors as intensity, quantity and distribution of rainfall; soil type; vegetation cover; and relief.

Bed load in a stream is mainly derived from gully erosion, streambank erosion and channel degradation. The quantity of bed load in a stream at any time depends on the hydraulic characteristics of the flow and soil surface (Leaf and Henderson 1966).

Vegetation may protect a streambank in at least three ways (Parsons 1963). Perhaps the most important of these is the reduction of water speeds and tractive forces at the soil surface to a value below that required to entrain particles. Second is the protection given to the bank material as a buffer against ice, logs and other transported materials. Third, close-growing vegetation will contribute to bank stability, within a narrow range of conditions, by inducing deposition. Subsequent to a rare flood that has caused damage but not complete destruction to the vegetative cover, the deposition that occurs in minor floods helps to maintain the bank.

Logging debris in the streams can divert stormflow from the channel to the road and/or the streambank, resulting in excessive erosion. Rice and Wallis (1962) reported that 13 percent of 3,000 feet of stream channel measured showed severe logging disturbance. In most cases, bulldozers had scoured or filled the former channel. Buffer strips of vegetation were found to be effective in reducing logging debris in the stream channel and stabilizing the streambanks.

Suspended Organic Material

Several forest practices can introduce living and dead particles of vegetation into streams. This organic debris is also contributed naturally and through the stream system in somewhat the same way as the inorganic materials, such as silt or gravel. Coarse debris of this type may have a relatively long period of residence in or near the channel awaiting slow decay and weathering. Some of it moves much more rapidly through the system and some is incorporated in the beds and banks of the channels. In all cases the material eventually decays. This decay of materials can degrade water quality by decreasing dissolved oxygen in the water and by releasing organic solutes during leaching.

Lammel (1972) described the natural debris accumulation in five small streams in western Oregon. He found that total residue increased after clearcut logging in all streams except one with a wide (50 m) buffer strip. Clearcutting increased residue volume 1.2 times over what it had been prior to logging near the stream with a light buffer strip. Residue volume was about 3.3 times greater along a stream where conventional high lead logging was used with no buffer strip.

Meehan et al (1969) noted that the number of large pieces capable of jamming two Alaska streams increased during four years of patch cutting. One watershed was about 20 percent logged and debris in the stream channel increased by 23 percent. In the second watershed, about 25 percent of the area was logged and debris in the stream channel increased by 60 percent. Debris in an unlogged watershed nearby increased about 7 percent during the same period.

Directional falling of trees can prevent debris accumulation in the streams. Froehlish (1973) reported that logging, especially at the tree falling stage, can produce large changes in debris loads. When the direction of falling was controlled by tree pulling, the quantity of material reaching the channel was reduced to a very small amount. On steep and broken ground tree pulling can be used to advantage. Buffer strips were found to be effective barriers even when they were not continuous or of large widths.

Burwell (1970) also noted that falling trees uphill using a truck-mounted donkey and climber to attach the line, prevents breakage and distributes limbs and tops on slopes instead of in stream bottoms. Savings such as increased safety, lessened breakage, reduction of slash to eliminate burning and enable quicker regeneration, and reduction of expensive creek cleaning may more than offset initial additional costs.

Log or debris dams are common in the salmon spawning streams of southeast Alaska, and often affect streamflow and streambed topography (Helmers 1966). Log-debris dams intensify streambed instability, especially during floods, and can reduce salmon production in otherwise favorable areas by increasing gravel movement which reduces egg and larvae survival. Debris dams may also affect spawning salmon as a migration barrier. Chapman (1962) reported that when debris was not removed from a stream after logging, spawning salmon decreased by 75 percent because of the migration barrier.

In summary, logging, especially at the tree falling stage, can produce large changes in debris loads. Care exercised during logging to control the direction of falling and protect streams can reduce debris accumulation in the streams . Buffer strips have been found to be effective debris barriers.

Dissolved Organic Material

The storage of logs in freshwater streams as well as saltwater estuaries and bays can result in the deposition of large quantities of bark and wood residue on the bottom near log dump sites and log raft storage areas. In addition to bark and wood accumulation, leachates diffuse out of the logs into the water. Some of the leachates are toxic to fish and other aquatic organisms. The taste, color and odor of the water can also be degraded due to high concentrations of organic solutes.

The quantity of bark lost from logs during handling in the water is highly dependent on the particular activity (Hansen 1971). As shown in Table 5, free-fall dumping of Douglas-fir logs resulted in an average bark loss of 17 percent. Vertical hoisting removed 8 percent of the bark. But during rafting and storage only 5 percent of the bark was lost. Similar studies of ponderosa pine indicated that cumulative losses for both unloading and storage were approximately 6 percent (Hansen 1971). Although limited data is available it has been suggested that losses of bark from bundled logs is likely to be lower than that of non-bundled logs because of the reduction of log surface area exposed to abrasion (Hansen 1971). It is anticipated also that bark losses may be larger for storage areas subject to strong waves or current action in contrast to storage facilities in sheltered waters.

The rate at which bark sinks when placed in water is governed by bark density, water absorption rate and particle size. Laboratory data collected by Schaumburg (1970) indicated that small particles of ponderosa pine bark tends to sink faster than the larger particles. Also, in general, ponderosa pine bark tends to sink faster than Douglas-fir bark.

The area of the bottom covered by bark tends to be highly variable depending on the method used for dumping, the length of time the dump site is in use and the degree of flushing action. Pease (1974) reports that bark may cover the bottom within a radius of 50-200 feet of the dump site. Currents can result in bark being deposited on beaches where its aesthetic impact is often significant.

Table 5. Douglas-fir bark loss during log handling operations. (After Hansen 1971)

Activity	Average Percent Bark Loss
Land Handling and Transport to Dump Site	18 - 25
Free-Dumping	17
Vertical Hoisting	8
Rafting and Storage	5

The State of Alaska (1971) has inventoried all log handling and storage facilities in Alaska, and Ellis (1973) has reported on inspections of log dump facilities located in Alaska. Facilities examined included sale area dump sites, storage areas for log rafts, mill storage, and sorting sites. Several of the sites in Alaska had been used intensively for two to five years and then abandoned. Others had been in continuous use for several years. The quantity of logs dumped and handled at the various sites inspected ranged from 10 to well over 150 million board feet.

With but few exceptions, large quantities of bark, fragments of wood, steel bands, and broken sections of wire rope on the bottom were found in the immediate vicinity of the dump site. The area covered by debris tended to be highly variable, but in general, the concentration decreased at locations further removed from the dump site. In areas characterized by large accumulation of bark and debris, the populations of marine organisms were considerably smaller than those of adjacent areas free of debris. Somewhat lower quantities of debris were present at dump sites subject to the flushing action of moderate tidal currents. A wide variety of marine organisms were found to reside in areas free of debris.

Hansen et al (1971) showed that log debris from rafting and dumping sites caused physical damage to estuarine habitats in Alaska. They found that the bottom of a dump site, which had been abandoned for seven years, was covered with two feet of decomposing organic debris. Marine animals were scarce there but abundant in adjacent areas.

The biodegradation of bark on the bottom in the vicinity of log dump sites results in the consumption of oxygen from overlying waters (Schaumberg 1973; Pease 1974). The increased oxygen demand required for bark decomposition is reported to range from 30 to 70 percent greater than that of areas free of large deposits of bark (Hansen 1971). Oxygen concentrations below 6 mg/liter, have been reported in log storage waters, particularly those which have been used for an extended period of time and not subject to vigorous flushing action (Schaumberg 1973; Pease 1974). Due to the complex chemical composition of bark and to the low water temperature at many storage sites, the rate of bark decomposition is low at many dump sites in the Pacific Northwest.

Schaumberg (1973) reports that leachates from logs in water storage contains mostly organic substances which exert both a chemical and biochemical oxygen demand. The leachates are primarily tannins and lignin-like substances which impart a brownish color to the receiving water. The added color can be aesthetically undesirable.

Narver (1970) concluded that soluble organic materials such as woodsugars, tannins, and lignin-like substances leached from logs can produce a considerable COD (chemical oxygen demand) along with yellow and brown colors in water. Ponce (1974) noted that the concentration of organic material needed to produce toxic effect was so high that oxygen depletion probably would be responsible for death of guppies and steelhead trout fry long before the leachate had effect.

Schaumberg (1973) has reported on the results of laboratory studies of the leaching of sections of both ponderosa pine and Douglas-fir logs. His data indicates that more color-producing and soluble organic substances are produced from ponderosa pine logs than from comparable Douglas-fir logs. When held in non-flowing water, leachates emerged at a relatively constant rate for a period of up to 80 days. When immersed in a flow-through system, however, the rate of leaching was substantially higher at the outset but declined after 20 to 30 days. No studies were conducted on high rate flow-through systems characteristic of some streams and estuaries.

Pease (1974) reported higher leachate concentrations and lower levels of dissolved oxygen for log storage sites in Alaska. Higher leachate concentrations were observed at sites subject to low rates of tidal flushing action and longer periods of log storage. Also, leachate concentrations tended to be highest in layers of water within the interspaces of log rafts.

A study by Graham (1970) on the quantity and properties of substances leached from logs floating in water and the rate of leaching of these substances, reported that ponderosa pine logs contributed measurably greater quantities of soluble organic materials and color-producing substances than Douglas-fir logs. Leaching rate appeared to be affected by the concentration of soluble organic materials in the stagnant holding water. In flowing water, the leaching rate was nearly constant. Extrapolation of laboratory test data to field conditions resulted in a prediction that 800 pounds of COD per day would be contributed by approximately eight million board feet of floating logs to a typical log storage facility.

Schaumberg (1973) reports that leachates are relatively non-toxic to salmon and trout fry for exposure periods of up to four days. Pease (1974) reports that it required 12 hours for the most toxic wood leachates (spruce) to kill one-half of the test fish. As indicated above, leachate concentration tends to be highest in localized areas in close proximity to log rafts. As Pease (1974) points out, it is doubtful that mature fish would remain in an area of high leachate concentration for a period of 12 hours before detecting the higher concentration and low oxygen concentration and swim away. Consequently, although log leachates are toxic to fish, it is doubtful under normal circumstances that large kills of mature fish are to be expected.

Leachates, on the other hand, can reach more highly-concentrated levels near the bottom where bark and wood fragments concentrations are higher. In such circumstances they have an impact on the number and diversity of benthic organisms (Pease 1974). Log storage in reproduction areas or where the benthic zone is critical at some stage of an organisms life-cycle, can result in significant adverse effects.

Atkinson (1971) studied the acute toxicity of Douglas-fir, ponderosa pine and hemlock logs to chinook salmon and rainbow trout in fresh water. He found that hemlock leachate was not measurably toxic to trout and salmon fry after a 96-hour period. His leachate solution was composed from water soaked with a small hemlock log for several days. He did find that 20 percent by volume of Douglas-fir leachate was toxic after 96 hours.

Buchanan (1970) tested the toxicity of spruce bark, hemlock bark and barite ore to Dungeness crab and shrimp larvae. He found that spruce bark had the highest toxicity of these three materials tested. He defined EC_{50} as the concentration of barite ore, hemlock bark or spruce bark that produced a designated effect on 50 percent of the test animals. When cessation of swimming was used as a criterion of toxic effect, the 24-hour EC_{50}'s were 43 and 190 mg/l, respectively. Hemlock bark proved to be the least toxic.

Buchanan and Tate (1973) tested the acute toxicity of sitka spruce and western hemlock bark to pink salmon fry, pink shrimp adults and larvae, and Dungeness crab larvae. The 96-hour EC_{50}'s for spruce bark leachates to larval shrimp, adult shrimp and larval crabs, with death as the criterion, were 415, 205 and 330 mg/l, respectively. Using loss of swimming as the criterion of toxic effect, the 96-hour EC_{50}'s for larval shrimp and larval crabs were 155 and 225 mg/l, respectively. Spruce bark particles were found to be two to six times more toxic than leachates to shrimp larvae.

Dissolved Inorganic Material

Soil properties and vegetative characteristics that influence the hydrologic stability of the forest floor can be altered when forests are clearcut and the logging residue burned. An immediate effect of such treatment is the baring of the soil surface, thereby making it vulnerable to the impacts of overland flow and raindrop splash during storms. The interception and shading effects of the forest cover are negligible for several years following clearcutting and burning.

As water runs over the surface of the soil, plant nutrients are dissolved and removed from the site. In addition, the soil which is eroded includes attached nutrients, which are also lost from the site. The amount of the surface runoff, the amount of eroded material or sediment produced by this runoff, and nutrient loss must be considered when evaluating the effects of clearcutting and burning forest lands.

Slash, a common by-product of a clearcut logging as well as other timber harvesting techniques, is sometimes deposited directly in stream channels. In general, the large material is removed or disposed of. Finely divided material, however, such as needles, leaves and broken twigs, may remain. This material can be responsible for a reduction in dissolved oxygen (DO) concentration (Narver 1971).

Chemical nutrients in the stream are but one aspect of the interface between the forest and the stream. The utilization of chemicals by stream biota is undoubtedly also related to other changes in the stream following timber harvest. Additional solar energy adsorbed by the stream, resulting from reduction of cover over the stream increases the production of aquatic plants. The structure of the community of organisms and their metabolic rate may change due to elevated stream temperature. Sedimentation and organic materials may alter the nutrient supply of the stream. Decomposition of organic materials deposited in the stream utilizes dissolved oxygen from the stream water--sometimes reducing the concentration to levels critical for the survival of aquatic organisms.

NUTRIENTS

Cycling of nutrient elements between atmosphere, plants, soil and water is one of the most important processes in a forest ecosystem. The nutrient cycling process may be altered by logging and burning (Fredricksen 1971) or by complete destruction of the vegetation covering a watershed (Likens _et al_ 1970). The degree to which the nutrient cycling process is disrupted depends on the nature of the soil and how it was affected by the treatment, the soil microflora and fauna, the degree of vegetation removal and the precipitation pattern (Brown _et al_ 1973).

Following logging, nutrient concentrations in stream water are governed by three characteristics that describe a watershed, i.e., soil, vegetation and climate. Vegetation characteristics such as species composition influence the rate of nutrient uptake, and the rate of revegetation after a watershed disturbance influences the rapidity with which recycling begins and nutrient loss diminishes. Several characteristics of the soil such as porosity and texture, determine the pathway and the rate of water movement in or over soil. These same characteristics also influence soil erodibility and the tenacity with which the nutrients are held in the soil matrix. The form, chemistry, amount and intensity of precipitation influence the rate of leaching.

Clearcutting tends to deplete the nutrients of a forest ecosystem by:

1) reducing transpiration and thereby increasing the amount of water passing through the system;
2) simultaneously reducing root surfaces capable of removing nutrients from the leaching water;
3) removal of nutrients in forest products;
4) adding to the organic substrate available for immediate mineralization;
5) in some instances, producing a microclimate more favorable to rapid mineralization.

These effects may be significant with other types of forest harvesting, depending on the proportion of the forest removed. Loss of nutrients may be accelerated measurably in cutover forests where the soil microbiology leads to an increase of dissolved nitrate in leaching waters (Bormann _et_ _al_ 1968).

Clearcutting on sites having one or more of the following soil features may be particularly vulnerable to excessive nutrient losses: shallow to bedrock; thin layers of unincorporated humus overlaying infertile mineral horizons; and coarse skeletal soils on steep terrain (Pierce _et_ _al_ 1972).

Major losses of nutrients from terrestrial ecosystems result from two processes: (1) particulate matter removal accomplished by erosion and transportation in surface drainage water, and (2) solution removal accomplished by dissolution and transportation of solutes by surface and subsurface drainage water (Bormann et al 1969).

The vegetation on a small watershed-ecosystem in Hubbard Brook Experimental Forest was cut in order to determine the effects of removal on nutrient cycles. Bormann et al (1968), reported that relative to undisturbed ecosystems, the area denuded exhibited accelerated loss of nutrients: nitrogen lost during the first year after cutting was equivalent to the amount annually turned over in an undisturbed system, and losses of cations were 9, 8, 3 and 20 times greater for Ca^{++}, Mg^{++}, Na^{+} and K^{+}, respectively, than similar losses from comparable disturbed systems.

Large increases of nutrient levels in a small stream in the Hubbard Brook Watershed after forest cutting and three successive summers of herbicide application were reported by Likens et al (1970). The results of this study while in an artifically created situation have raised several questions about the impact of clearcutting on both productivity of forest soil and the quality of water from clearcut watersheds. Nitrate concentrations were 41 fold higher than the undisturbed condition the first year and 56 fold higher the second year. The nitrate concentration in stream water exceeded, almost continuously, the health levels recommended for drinking water. Sulfate was the only major ion in stream water that decreased in concentration after deforestation. Average stream water concentration increased by 417 percent for Ca^{++}, 408 percent for Mg^{++}, 1,558 percent for K^{+}, and 177 percent for Na^{+} during the two years subsequent to deforestation.

Reinhart (1973) reported that for the two years following clearcutting in New Hampshire, about 85 lbs/acre of nitrate-N and 80 pounds of Ca were discharged in streamflow. Losses after cutting amounted to about 2 percent of the N capital available in the ecosystem and 4 percent of the Ca. Losses in the central and southern Appalachians were far less. The difference between the New Hampshire and other results seems to be associated with the nature of podzol soils. Pierce et al (1972), noted that substantial changes in ion concentration were found in all streams draining clearcut areas in the White Mountains of New Hampshire. Indications are that clearcutting on shallow, infertile, podzolized soils can result in nutrient losses for several years after exposure.

Fredriksen (1971) studied the nutrient release after clearcut logging of an old-growth Douglas-fir forest in the Oregon Cascades. Following timber harvest and slash burning, loss of nutrients cations increased 1.6 to 3.0 times the loss from the undisturbed watershed. A surge of nutrients that followed broadcast burning contained concentrations of ammonia and manganese that exceeded federal water quality standards for a period of 12 days. Annual nitrogen loss following burning averaged 4.6 lbs/acre and 53 percent of this was organic nitrogen contained in sediment. Inorganic nitrogen dissolved in the stream made up the remaining part. Annual loss of nitrogen from the undisturbed forest was very small: 0.16 lbs/acre. Later, Fredricksen (1972) noted that even though 170 and 135 cm of water passed through this Douglas-fir ecosystem, for the two years of the study period the ecosystem conserved nitrogen effectively as indicated by an average annual dissolved nitrogen outflow of 0.5 Kg/ha from an annual average input of 1.0 Kg/ha in precipitation. There was a small annual net loss of phosphorus (0.25 Kg/ha). Average annual net losses of calcium, sodium, magnesium and potassium were: 47, 28, 11, and 1.5 Kg/ha, respectively. Silica loss of 99 Kg/ha-yr was the largest of all constituents and came entirely from within the forest system.

Brown, et al (1973), studied the effect of clearcut logging and slash burning on nutrient losses from small watersheds in the Oregon Coast Range for two years before and for two years after logging. No change in the concentration or yield of nitrate nitrogen, phosphorus or potassium was observed after logging in a patch cut watershed. In a clearcut logged and burned watershed, maximum nitrate nitrogen concentrations increased from 0.70 to 2.10 mg/l. Nitrate nitrogen concentrations returned to prelogging levels by the sixth year after logging. Yield of nitrate nitrogen increased from 4.94 to 15.66 Kg/ha the first year after treatment. Potassium concentration increased markedly after burning from about 0.60 to 4.40 mg/l but returned to prelogging levels within two months. Phosphorus concentrations were unchanged.

In the larch and Douglas-fir forest type of western Montana, watersheds were clearcut and the logging debris broadcast burned (DeHyle and Packer 1972). They report that logging and burning temporarily impaired watershed protection by increasing overland flow and soil erosion. The soils were developed from the Belt formation and occurred on gentle to steep slopes. Vegetal recovery returned conditions to near prelogging status within four years. The increase in plant nutrient losses, which occurred in the sediment and the overland flow during the denuded period, represented a small fraction of the available nutrients on these sites.

Marks and Bormann (1972) found that forest regrowth tended to minimize nutrient losses from the ecosystem and thus promote "a return to steady-state cycling characteristic of a mature forest." They sampled stands of pin cherry which revegetated the site following clearcutting and found, among other things, that the standing crop at age 14 held about 180 lbs/acre of N and 160 pounds of Ca. They estimated that the annual uptake of N in the 4- and 6-year old stands was about 50 percent greater than in the more-or-less mature, undisturbed ecosystem at Hubbard Brook. Perhaps equally important is the shading of the forest floor by new vegetation and the resulting decrease in surface temperature and rate of organic matter decomposition.

In summary, nutrient losses from most of the forest of the Northwest after clearcutting appear to represent minor short-term problems, both in terms of the terrestrial and aquatic systems. Rapid revegetation and heavy deep soils tend to preclude significant nutrient loss. However, where (1) shallow or erosive soils exist, (2) revegetation is not rapid, or (3) the impacts become cumulative, the effects, particularly those associated with water quality, could be significant.

OXYGEN

The character and productivity of aquatic ecosystems in streams is significantly influenced by the concentration of dissolved oxygen (DO). Several forestry practices change the DO concentration, particularly in small streams, either directly or indirectly. Changes in stream temperature brought about by the removal of streamside vegetation, increases in nutrient concentrations as a result of harvesting, and the accumulation of logging debris in the stream are some of the more important factors which effect DO concentration.

Dissolved oxygen, like temperature, is a primary regulator of biologic activity in an aquatic ecosystem. Dissolved oxygen present at any time in a stream is a function of the water temperature (Churchill _et al_ 1962), which limits the saturation concentration; and channel characteristics, such as slope, roughness and cross-section, which control the rate of oxygen exchange between water and air.

Aquatic microorganisms also influence the amount of oxygen in stream water. These organisms utilize organic materials in the stream as an energy source and extract oxygen from the water in the process. Organic material can be characterized by the amount of oxygen required by microorganisms for decomposition. This amount is called biochemical oxygen demand (BOD).

The dissolved oxygen content and the velocity of flow of the intragravel water influences the well-being of embryos or alevins in spawning streams. Coble (1961) planted fertilized trout eggs in a stream and measured permeability, apparent velocity and dissolved oxygen. About one month after hatching he found a positive correlation between velocity and survival and between dissolved oxygen and survival. He observed also that high dissolved levels of oxygen and high stream velocity usually occurred together.

Hermann _et al_ (1962) also reported that growth and food conversion rates of juvenile coho salmon decreased slightly with reduction in dissolved oxygen of surface water from 8.3 to 5 mg/l and decreased abruptly with further reduction. Many fish died and the survivors lost weight at dissolved oxygen levels of 2.1-2.3 mg/l.

Leaves from deciduous forests may produce an organic oxygen demand in otherwise unpolluted streams (Slack and Feltz 1968). Although the rate of litter production from a deciduous forest is greatest during the autumn leaf fall period, leaves are part of the continuing load of organic detritus which streams ultimately deposit in deep pools, reservoirs, or other receiving bodies. Organic detritus stored in bottom sediments is an almost constant supply of organic material to a stream.

The uptake of oxygen by tree leaves extends over relatively long periods. In laboratory studies, Chase and Ferullo (1957) showed that after one year, maple leaves demanded about 750 mg O_2/g of their initial dry weight, but oak leaves and pine needles required about 500 mg O_2/g of their initial dry weight. The oxygen uptake was rapid; by day 100, maple had achieved about 70 percent, and oak and pine had achieved about 55 percent of the demand exerted in one year.

Forest practices can influence the amount of oxygen in streams in several ways. Clearcutting alongside a stream may increase stream temperature, thus lowering the saturation concentration. In one extreme case, maximum temperatures increased from about 57°F to about 85°F and the saturation concentration dropped from 10.26 ppm to 7.44 ppm (Brown 1972).

Logging debris often accumulates in the channels of clearcut watersheds, particularly if logs are yarded across the stream channel. Once in the stream, debris can influence oxygen levels in two ways: (1) Finely divided debris, such as needles, leaves, small branches or bark contains large amounts of simple sugars which are leached rapidly and consumed by the microorganisms. These materials exert a high BOD. (2) The restriction of water by debris dams reduces reaeration. Ponding also increases stream surface area and accentuates temperature increases.

The impact of Douglas-fir needles and twigs, western hemlock needles and red alder leaves on dissolved oxygen and thus on the quality of mountain stream water was studied by Ponce (1974). The mean COD (the total quantity of oxygen required for completely oxidizing the material), 90-day BOD, and BOD rate coefficients were, respectively, 454 mg O_2/g, 110 mg O_2/g, and 0.125 for Douglas-fir needles, 947 mg O_2/g, 110 mg O_2/g, and 0.056 for Douglas-fir twigs, 570 mg O_2/g, 200 mg O_2/g, and 0.049 for western hemlock needles, and 888 mg O_2/g, 286 mg O_2/g and 0.047 for red alder leaves. Toxicity of a leachate extracted for each species was determined on guppies and steelhead trout fry. The concentration of material needed to produce toxic effects was so high that oxygen depletion probably would be responsible for death long before the leachates.

Hall and Lantz (1969) studied the effects of logging on the habitat of coho salmon and cutthroat trout in coastal streams of Oregon. They reported a substantial reduction in the DO concentration of the surface and intragravel water of the clearcut watersheds. DO concentrations from late spring through most of the summer were too low to support salmon and trout in one third of the stream available to the salmonids. Juvenile coho salmon placed in live-boxes survived less than 40 minutes. The lowest oxygen concentration reported, 0.6 mg/l, was observed in a pool dammed by debris. During this period, oxygen concentration of the control stream and the stream draining the patch cut watershed remained at levels near saturation. Upon the removal of large debris from the channel and establishment of a free-flowing condition, the DO concentration rapidly returned to near prelogging conditions in the surface water. Intragravel oxygen concentrations, however, remained about 3.0 mg/l lower than the prelogging concentrations for the next two years and continued to decline over the next four years to levels less than 2.0 mg/l at several locations. Part of the decline of intragravel oxygen concentrations can be attributed to long-term BOD of organic material included in the gravel. It was concluded that the major problem, however, was associated with reduced circulation because of sedimentation of the gravel bed.

The storage of logs in water produces leachates with a significant quantity of high BOD substances. Atkinson (1971) found that the highest BOD, 2.36 g/ft^2 of log submerged surface area, was exerted by leachates from a ponderosa pine log stored with the bark removed. The study also included Douglas-fir and western hemlock.

In summary, logging debris and increased water temperature can lead to serious decreases in the oxygen concentration of stream water. However, dissolved oxygen levels can be improved during logging if shade is maintained and debris is kept out of the stream channel. Buffer strips can aid in controlling debris accumulation, and where these strips contain large trees they may serve as interceptors for debris sliding downhill. One benefit of a buffer zone along the stream is that it discourages logging across or through the stream channel. Improved logging techniques such as skylines, balloons and helicopters have been used to log near streams and at the same time minimize debris accumulation in the channel (Brown 1972).

Thermal Pollution

Stream temperature, as a water quality parameter subject to modification by silvicultural practices, is of prime importance to aquatic ecosystems. Thermal pollution, especially in coastal Oregon, has gained much attention. The streams and rivers of this area provide a habitat to valuable anadromous and resident fish species. Temperature increases can have a profound influence on dissolved oxygen, disease, increased competition from undesirable species and vitality. Direct mortality and an increase in stream eutrophication potential can also result from increased stream temperature.

Daily temperature variation in undisturbed streams is approximately 2.2° C (4° F) or more. This value has been observed to increase to about 5.6° C (10° F) or higher when all shade along the stream has been removed. In instances where the natural stream temperatures are already in the upper range of fish requirements, the removal of streamside vegetation and exposure of the stream to direct solar radiation can raise temperatures above the tolerance limits of most salmonids.

Silvicultural practices can change or influence the non-climatic factors which affect the amount of heat received at the stream surface. These factors include:

1) Vegetation

2) Physiography and Hydrology

   a. topography
   b. stream channel characteristics
   c. inflow of surface and groundwater
   d. area, depth and velocity of the stream

VEGETATION

Increases in stream water temperature are caused primarily by increased exposure of the stream to direct solar radiation as a result of removing streamside vegetation (Brown 1966, 1967, 1970). Shade removal may increase radiation loads by six to seven times (Brown 1970). Air temperature and the cooling effects of evaporation are much less important than solar radiation in controlling temperature on small, unshaded streams. Brown (1970) found that solar radiation accounted for over 95 percent of the heat input during the midday period in midsummer.

Shading is highly dependent on the type of vegetation along stream banks. A mature stand of conifers, with much of the lower bole free of limbs, may offer only partial shade, whereas a younger stand of trees with well-developed crowns may provide much more shade. Understory species, such as hardwoods or brush, generally provide very adequate shade for small streams.

Spacing of vegetation also affects light intensity. If vegetation is not spaced closely enough, the stream may not be effectively shaded even though the vegetation is of sufficient height. Tables 6 and 7 show how tree density or stocking affect the light intensity (Resler n.d.).

Table 6. Stand density effects on light intensity. (After Resler n.d.)

	Percentage of Fully Stocked Stand Removed	Light Intensity (% of open)
Stem density	0	8
	25	14
	50	26
	75	55
Canopy closure	0	4
	25	6
	50	16
	75	43
Basal area	0	10
	25	15
	50	27
	75	52

Table 7. Spacing effect on light intensity. (After Resler n.d.)

Spacing (ft)	Tree (number/acre)	Light Intensity
4 x 4	2721	15
6 x 6	1210	16
7 x 7	889	36
9 x 9	538	60

PHYSIOGRAPHY AND HYDROLOGY

Since the angle of the sun varies with latitude, vegetation that shades the stream effectively at the higher latitude is less effective at lower latitudes. Consequently, at lower latitudes, vegetative cover should generally be taller to provide adequate shade.

At certain times of the day, the topography on the south side of an east-west oriented stream is effective in shading the stream without any vegetative cover. But on north-south oriented streams, vegetative cover is needed on both sides of the stream. At midday, the vegetation which overhangs or is immediately adjacent to the stream is the most effective. Later in the day when the declination of the sun has changed, vegetation further from the stream can also provide shade.

Temperature change is directly proportional to the area of stream exposed and the duration of exposure, and indirectly to the volume of water. The temperature change will be higher for wider streams with shallow water than narrow streams with deep water. Brush or hardwoods can effectively shade small narrow streams, whereas conifers or taller vegetation are needed to fully shade wide streams.

The stream gradient has a direct influence on the flow speed. The higher the flow rate, the shorter the exposure time. Therefore, fast-flowing streams heat up less rapidly than slow-flowing, low gradient streams.

The type of stream bottom or channel can strongly influence stream temperature. Rocky bottoms act as a heat sink storing the sun's energy. As a consequence, stream temperature does not rise nor cool as rapidly. In contrast, gravel, sand or coarse fragments will both heat and cool more rapidly.

FOREST PRACTICES

The temperature change brought about by logging is directly proportional to the amount of exposure to solar radiation the stream surface experiences, and the heat load applied to the surface area. Recent studies suggest that stream temperatures are most subject to change during periods of low flow after removal of a high percentage of streamside vegetation. Therefore, any silvicultural activity that exposes a large area of the stream surface to sunlight can cause substantial changes in water temperatures, especially during low flow periods.

Studies on stream temperature changes following logging have been conducted on the H.J. Andrews Experimental Forest in the Oregon Cascades for more than a decade (Anderson 1973). Levno and Rothacher (1967) reported large temperature increases in two experimental watersheds after logging. The shade provided by riparian vegetation in a patch cut watershed was eliminated by scouring after large floods in 1964. Subsequently, mean monthly temperatures increased 7-12°F from April through August. Average monthly maximums increased by 4°F after complete clearcutting on a second watershed. The smaller increase in the completely clearcut watershed was the result of shade from the logging debris that accumulated in the channel.

Brown and Krygier (1970) have recorded one of the largest changes in stream temperature after clearcutting in Oregon's Coast Range. Two patterns of clearcutting were used. A 750-acre watershed was patch cut with three small clearcuts covering about 25 percent of the watershed. Clearcut boundaries were separated from perennial streams by buffer strips 50 feet to 100 feet wide. A second watershed of 175 acres was completely clearcut. They found no increase in temperature attributable to logging in the patch cut watershed, where buffer strips continued to provide shade for the stream. In contrast, an increase of 14°F in monthly mean maximum temperature was observed after complete exposure of the clearcut watershed. There was an annual maximum rise of 28°F on this small stream when discharge dropped to .001 cubic feet per second in late summer.

Studies were conducted by Brown et al (1971) on Steamboat Creek of the Oregon Cascades to determine the effects of logging on stream temperatures and to determine the effectiveness of varying densities and types of streamside vegetation for temperature control. They found that removing all shade from a stream course could increase water temperature 10°F and more, whereas the differences in stream termperature due to natural causes varied by approximately 4°F. Exposing 150 feet of one small stream increased the water temperature 13°F. They also recorded the impact of various degrees of shade reduction on stream temperature, including clearcutting with buffer strips.

Hall and Lantz (1969) noted that temperature increased progressively as the stream progressed through a clearcut. Temperature decreased about 6°F as the water passed through a somewhat shaded area of the stream channel, where streamside vegetation had been less severely affected by logging. They also found that slash burning increased the stream temperature from 55°F to at least 82°F. On a watershed where the fire was separated from the stream by a buffer strip, no significant increase in temperature associated with slash burning was observed.

Patric (1969) compared the effect of two clearcutting patterns on water quality. Temperatures were unaffected by clearcutting the upper half of one watershed. Clearcutting the lower half of the second watershed increased stream temperatures by up to 7°F.

Greene (1950) studied the effect of clearcutting on trout streams. He reported that maximum weekly temperatures recorded during May on a non-forested stream were 13°F higher than those recorded on a nearby forested stream. He noticed also that the maximum temperature dropped from 80° to 68°F after the non-forested stream meandered through 400 feet of forest and brush cover.

Helvey (1972) studied the first year effects of wildlife on water yield and stream temperature in north central Washington. He reported that maximum daily stream temperature was increased by as much as 10°F during late summer when streams were exposed to direct insolation. Levno and Rothacher (1961) report that the first year after slash was burned on a 237-acre clearcut watershed in the Cascade Range of Oregon, average maximum temperature increased 13°, 14° and 12°F during June, July and August, respectively.

Chapman (1962) checked comparable logged and unlogged drainages in Oregon's Alsea River Basin and found temperatures to be as much as 10°F greater in logged areas where riparian vegetation was completely removed.

Meehan et al (1969) reported a maximum increase in summer stream temperature of only 9°F after clearcutting on two watersheds near Hollis on Prince Wales Island, Alaska. The cool, generally overcast climate of southeast Alaska is probably the main reason for this relatively small change in stream temperature after logging. Meehan (1970) also noted that temperature increases after clearcutting in this region do not normally approach lethal limits for fish populations. However, the indirect effects of temperature increase, particularly in the case of resident fish populations, are not known. Salo et al (1973) examined the effects of logging on small streams in the Thorn Bay area of southeast Alaska. They found that stream temperatures increase much more rapidly in clearcut-logged than in unlogged study areas, and maximum stream temperature was reached 2.5 hours after peak solar radiation.

Swift and Messer (1971) measured the influence of six forest-cutting treatments on stream temperatures of small watersheds in the southern Appalachian Mountains. Where forest trees and all understory vegetation were completely cut, maximum stream temperatures in summer increased from the normal 66° to 73°F or more. Some extreme treatments raised temperatures more than 12°F above normal. Where stream bank vegetation was uncut or had regrown, summer maximums remained unchanged or declined from temperatures measured under uncut mature hardwood forest.

Water-temperature records through September 1968 were summarized by Blodget (1970) for 120 streams in the north coastal subregion of California. He presented current and historic stream temperatures for correlating periodic and thermograph records and for analysis of the factors affecting these temperatures. The summary data for each site is useful in providing guidelines for the establishment of thermal water-quality guidelines.

Brazier and Brown (1973) defined the characteristics of buffer strips that are important in regulating the temperature of small streams and described a method of designing buffer strips that are intended to minimize changes in temperature and at the same time minimize the amount of commercial timber left in the strip to provide the necessary shade. The results led to several interesting conclusions about designing buffer strips for temperature control purposes.

1) Commercial timber volume alone is not an important criterion for water temperature control. The effectiveness of buffer strips in controlling temperature changes is independent of timber volume.
2) Width of the buffer strip, alone, is not an important criterion for control of stream temperature. For the streams in this study, the maximum shading capability of the average strip was reached within a width of 80 feet; 90 percent of that maximum was reached within 55 feet. Specifying standard 100 to 200 foot buffer strips for all streams, which usually assures protection, generally will include more timber in the strip than is necessary.
3) Angular canopy density is correlated well with stream-temperature control. It is the only single criterion the forester can use that will assure him adequate temperature control for the stream without overdesigning the buffer strip.

Increases of suspended sediment can alter aquatic environments by changing the spectral properties of streams and heat radiation. Suspended sediment can alter the rate of temperature change in river waters. This is particularly significant in deep rivers and lakes where thermal stratification of the water produces a stratification of the silt load.

WATER TEMPERATURE CRITERIA FOR FISH

The most significant implication of the warming of small headwater streams is the potential degradation of water quality for trout habitat. Fishery managers generally agree that water temperatures for trout should remain consistently below 70°F and that optimum trout production occurs in streams which do not exceed 68°F, even for short periods of time (Stroud 1967). Trout can exist temporarily in warmer waters, but the physiological stress may reduce their resistance to predation and disease or inhibit their feeding and reproduction, any of which could eventually eliminate the fishery (Brett 1956).

Brett (1956) noted that the upper and lower limits of temperature which a fish can withstand define the extremes of its tolerable environment. Lethal temperatures and thermal tolerances vary from species to species. Salmonids have the lowest thermal tolerance, with the maximum upper lethal short term exposure temperature barely exceeding 77°F.

The following table summarizes information taken from the 1975 preliminary draft publication entitled Quality Criteria for Water to be published by U.S. Environmental Protection Agency, Washington, D. C.

TABLE 8. Maximum weekly average temperatures for growth and short-term maxima for survival for juveniles and adults during the summer (Centigrade and Fahrenheit).

Fish Species	Growth[a]	Maxima[b]
Rainbow Trout	19 (66)	24 (75)
Brook Trout	19 (66)	23 (73
Coho Salmon	18 (64)	24 (75)
Sockeye Salmon	18 (64)	22 (72)
Largemouth Bass	32 (90)	34 (93)
Bluegill	32 (90)	34 (93)

a -- Calculated according to equation: Maximum weekly ave. temp. for growth = optimum for growth + 1/3 (ultimate incipient lethal temp.- optimum for growth).

b -- Based on temperature (°C) = 1/b (LOG_{10} TIME(Min.)-a)- 2°C, acclimation at the maximum weekly ave. temp. for summer growth, and data in Appendix II-c of Water Quality Criteria, 1972 (NAS, 1974)

SUMMARY

Silvicultural practices and logging can significantly increase the temperature of small streams. Shade removal affects solar radiation and may increase radiation loads by six to seven times (Brown 1970). Temperature increases from 6 to as much as 28°F have been reported. The magnitude of the increase is dependent upon stream characteristics such as flow, surface area exposed to sunlight, and the amount of radiation received from the sun.

Increases in the temperature of small streams can be prevented during and after logging by leaving a protective strip of vegetation alongside the stream to provide shade. The efficiency of this strip in controlling water temperature has been demonstrated in several studies (Brown and Krygier 1970, Brown _et al_ 1971, Swift and Messer 1971). Various guidelines for the protection of streams in logged watersheds have recommended buffer strips for temperature control (Federal Water Pollution Control Administration 1970, Lantz 1971, Society of American Foresters, Columbia River Section, Water Management Committee 1959, and USDA n.d.). These are discussed in Chapter 5.

One approach to managing water temperature is to predict the temperature changes that might result from various silvicultural systems and size of cutting units. Brown (1966, 1969) has developed a technique by using an energy budget for predicting temperature changes of small streams once the streamside vegetation has been removed.

CHAPTER 5
PLANNING AND MANAGEMENT

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PLANNING AND MANAGEMENT

Previous sections of this report have outlined background information for the region, described the forest practices utilized in the Pacific Northwest, and presented research summaries concerning the impacts of such forest practices on water quality. This section presents a summary of planning and management methods which represent the state-of-the-art for preventing water pollution from logging, residue management and reforestation. The purpose of this report is to summarize existing knowledge and technology, not to develop new methods.

Most of this section is based on, or has been excerpted from, the literature concerning water quality and forest management. However, a small percentage of the information presented, by necessity, results from the objective synthesization of available knowledge for the specific purposes of this report. In general, only the information directly relating logging, residue management and reforestation to water quality protection, and, in some cases, to fisheries, is presented.

Timber harvest has certain features that relate to water quality protection, as follows:

- the activity is dispersed and distributed over time
- physical, biological and chemical factors vary considerably from site to site and from subregion to subregion, resulting in widely varying water pollution potentials
- levels and types of quality control relative to timber management cover a wide range within the region

- the knowledge and field testing of methods for reducing water quality impacts vary significantly within the four-state study area
- the values and uses of similar water bodies differ from one subregion to another

These basic characteristics result in a greater potential for improving the quality of runoff from timber harvest areas through interdisciplinary planning than through remedial measures (e.g., catch basins). Certain standard requirements for timber harvesting can also be beneficial for water quality purposes, if the intrinsic qualities of the subregions are considered and the standards set accordingly. This section of the report includes subsections on information requirements, predicting effects, planning, sensitive areas and facilities location and silvicultural logging systems.

Information Requirements

Regardless of the planning/management approach to be utilized, an early investment in information gathering is required. Unless the information is already available, this represents a significant expenditure of time and money. For maximum usefulness, the information collection should begin a few years prior to the timber harvesting or road building. Such information might include basic data (e.g., stream flow and water quality), and/or existing reports for review purposes. It should be limited to that required by the planning methodology or management techniques envisioned.

Information requirements vary according to the specific use anticipated, and can be categorized as follows:

1) planning
2) prediction
3) impact monitoring

PLANNING

The following basic types of information (re: water quality) are generally required:

- topography
- soils and erosion hazards
- geology
- aquatic and/or marine biology
- water quality
- silviculture
- hydrology and geohydrology
- meteorologic
- engineering constraints
- logging system alternatives
- residue management alternatives
- institutional constraints (applicable laws)

In some instances, particularly involving small landowners, it may be prohibitive to adequately consider all the information types mentioned. Under such circumstances, the following six categories may suffice for site-specific planning:

- soil types, slopes and erosion hazards
- applicable state and federal water quality standards
- existing water quality and the fisheries to be affected
- silvicultural alternatives (clearcutting, selection cutting, etc.)
- logging system alternatives
- residue management and reforestation options

Federal land management agencies, such as the U. S. Forest Service, most state land agencies and some private forest management organizations, have compiled a considerable amount of information relating to forest lands within their jurisdictions. Such agencies also have expertise available to generate additional information for planning purposes, if necessary. However, not all agencies or landowners have this capability and may have to depend on outside sources or special studies. Table 9 presents a general list of potential information sources by category. This does not include private organizations that may be available, if new studies are required.

One important requirement for forest land planning is an inventory of the land systems involved. Wertz and Arnold (1972) have outlined the requirements for such an inventory, which is presented as Table 10.

In addition, the "System Outline" for the land base portion of an integrated environmental inventory as proposed by Wertz and Arnold (1972) is presented as Table 11.

Table 9: Categories and Potential Sources of Information Concerning Forest Management and Water Quality

Information Categories	Potential Sources
Topographic	U. S. Geological Survey Adjoining landowners (i.e., private, USFS, BLM) Local planning and zoning agencies Private mapping and aerial photography organizations Agricultural Stabilization and Conservation Offices (USDA)
Soils	U. S. Soil Conservation Service U. S. Forest Service (PNW & Intermountain Experiment Stations) County agricultural extension agents U. S. Geological Survey Adjoining landowners (i.e., private, USFS, BLM) Local planning and zoning agencies Universities
Geologic	U. S. Geological Survey State mining or geologic agencies Universities Adjoining landowners (i.e., private, USFS, BLM)
Aquatic and/or Marine Biology	State fish and game agencies National Marine Fisheries Service U. S. Fish and Wildlife Service
Water Quality	U. S. Geological Survey U. S. Environmental Protection Agency State environmental agencies State water administration agencies Universities
Tree Species, Forest Types and Stand Densities	State forest resource agencies Universities U. S. Forest Service County extension agents Local forest management associations Adjoining landowners (i.e., private, BLM)
Hydrologic and Geohydrologic	U. S. Geological Survey State water administration agencies Universities Water user organizations
Meteorologic	National Weather Service (U. S. Department of Commerce) Universities County agricultural extension agents

Table 10

(Adapted from: R. J. Alvis 1971)
Taken from: Wertz and Arnold 1972

THE LAND SYSTEM

I. Land components

A. Lithology

Kind and character of the bedrock.

B. Climate

Kinds, magnitudes, and frequencies of climatic occurrences.

C. Age

The time required to reach the present stage of development of lands.

D. Soils

The unconsolidated portion of the earth's land surface which can support plant growth.

E. Geologic structure

The arrangement, internal features, and shape of rock formations.

F. Landform

The shape and configuration of units of the earth's surface.

G. Plant ecology

Plant community identification and relationships with other elements of the environment.

II. Land system

A conceptual device which achieves an integrated overview of the relationships between geologic and climatic history, soils and plant ecology, as an aid in understanding land resources.

A. Relations of components to land system

Basic Components (Independent)	Lithology	Geologic Structure	Climate
		TIME	
Manifest Components (Dependent, related)	Soils	Landforms	Plant Ecology

Table 11

Taken from: Wertz and Arnold 1972

SYSTEM OUTLINE LAND BASE PORTION OF INTEGRATED ENVIRONMENTAL INVENTORY

Category	Name	Basis for Delineation	Size Range	Principal Application
VII	Physiographic Province	*Basic Elements* Structure, lithology, climate. First order stratification.	1000s of sq. miles	Nationwide or broad regional data summary.
VI	Section	*Basic Elements* Structure, lithology, climate. Second order stratification.	100s to 1000s of sq. miles	Broad regional summary. Basic geologic, climatic, vegetative data for design of individual resource inventories.
V	Subsection	*Basic Elements* Structure, lithology, climate. Third order stratification.	10s to 100s of sq. miles	Strategic management direction, broad area planning.
IV	Landtype Association	*Manifest Elements* Soils, landform, biosphere. First order stratification.	1 to 10s of sq. miles	Summary of resource information and resource allocation.
III	Landtype	*Manifest Elements* Soils, landform, biosphere. Second order stratification.	1/10 to 1 sq. mile	Comprehensive planning, resource plans, development standards, local zoning.
II	Landtype Phase	*Manifest Elements* Soils, landform, biosphere. Third order stratification.	1/100 to 1/10 sq. mile	Project development plans.
I	Site	Represents integration of all environmental elements. Units are generally not delineated on map.	Acres or less	Provides precise understanding of ecosystems. Sampling will be for defining broader units, for research, and for detailed on-site project action programs.

Certain basic hydrological and meteorological information is useful for water quality planning on forest lands as follows:

1) Annual (year-round) hydrographs for key locations for at least two years
2) Peak flow records for major flood flows for at least five consecutive years
3) Stream order definitions
4) Precipitation, including snow, preferably as isohyetal maps (annual average yield and maximum precipitation)
5) Critical event precipitation patterns (e.g., high intensity or long duration storms)
6) Erosion rates and sediment yields

In areas where streams or lakes present important forest values or may be affected by forest activities, limnological and stream habitat information is required. Base line aquatic life information involves a minimum of one-year data collection prior to the planned watershed disturbance. The frequency and seasonal variation of the sampling will depend on the life cycle of the species being monitored.

The U. S. Forest Service Northern Region has prepared a publication entitled "Lake Habitat Survey" (1974). This publication outlines guidelines for such surveys and is recommended as a basic reference for lake habitat information collection.

Platts (1974) presents an inventory method for aquatic systems in a publication entitled "Geomorphic and Aquatic Conditions Influencing Salmonids and Stream Classification," which should be generally applicable in the Northwest. Platts collected the following information:

1) Stream, pool and riffle widths to the nearest foot
2) Four stream depths at equal intervals across the stream to the nearest inch
3) Ratings, locations and features of pools
4) Stream channel surface material classifications
5) Cover, conditions and types of streambanks
6) Channel elevations and gradients
7) Geologic process groups and geomorphic types
8) Stream order
9) Whether the watershed was disturbed or undisturbed
10) Fish species, their numbers, and the length of fish occurring in selected streams between transects

The data requirements for planning are considerably different than for impact monitoring, particularly when the impact data is to be used in court as part of a legal proceeding. The most important characteristic of planning information is its comprehensiveness, which is required to establish the basic character of the area in question. Trends and unique or special intrinsic qualities require emphasis as opposed to the specificity required in impact monitoring. Planning involves general constraints and the avoidance of problem areas, so specific data are not as important as comprehensive data. Trend projections and broad scope statistical analyses are particularly useful in planning.

The reader is referred to "Three Approaches to Environmental Resource Analysis," a report prepared by the Landscape Architecture Research Office of the Graduate School of Design, Harvard University (1967).

The three planning approaches presented have general applicability to land use planning, and include planning method articles by G. Angus Hills, Phillip H. Lewis and Ian L. McHarg.

PREDICTION

The use of prediction techniques including computerized mathematical models, is discussed later in this section. Such analysis tools can be very useful if adequate data is available as input to models or methods, which have been developed for, or adapted to, the specific problem and project area under study. However, computerized models (not all models are computerized) have limitations including:

1) high initial cost for developing a new model, which may be prohibitive for a once-only use
2) the need for specialized personnel to develop, adapt and operate the model
3) the need for specific data inputs

However, when such models can be effectively utilized the accuracy and consistency of predicting water quality related impacts can be maximized. One of the most important considerations is the prior assembly of adequate input data.

The type of data required for prediction models generally varies somewhat from that required for planning and impact monitoring. The consistency of the data collection and analysis procedures is of secondary importance for planning information, provided the trends are reflected. Prediction methods, however, usually require very specific types of data and analysis, since computer programs or analytical procedures are developed assuming a specific type of data input. Occasionally, a nonspecified but similar type of available data can be utilized through program revision, provided the necessary data relationships can be defined, but this is the exception and not the general rule. Consequently, if such models are to be used, their data requirements must be determined well in advance.

The data most often required for models related to water quality and silviculture generally fall into one of the following categories:

1) hydrology
2) water quality
3) erosion rates and sediment yields
4) precipitation
5) aquatic or marine biology
6) cover type and density

Certain considerations are important for each of the above types of data, including:

a. length of data collection period required for adequate significance
b. collection pattern or sampling network
c. critical periods requiring sampling (e.g., spawning)

Hydrologic

Hydrologic models involving frequency of occurrence, e.g., peak flood flows, require a minimum of three to five years of data, preferably ten to fifty years. For this reason, it is advisable to use existing streamflow gaging stations with long-term records, if such are available. The location of data collection stations should reflect the normal and altered situations.

Simulation models generally require more types of data but can involve shorter time periods. Most hydrologic data is collected continuously.

Water Quality

Water quality data collection is often coordinated with hydrologic data collection networks, but continuous data is not usually taken for water quality prediction modeling purposes. "Grab" sampling for select parameters at critical periods is the most common, although not always adequate, approach.

The water quality parameters generally significant to silvicultural activities include:

1) dissolved oxygen and biological oxygen demand
2) nutrients
3) temperature
4) turbidity and/or suspended solids

Erosion Rates and Sediment Yields

Models to describe erosion processes are based either on empirical equations or are constructed from first principles using Newton's laws of motion, the laws of viscous forces, and some of the basic concepts of fluid mechanics. Because of the complexity of developing models from first principles, most of those that have been developed, including the equation developed by Megahan (1974), are of an empirical basis.

Typically, one or two constants appear in such equations, or models, that are characteristic of a particular soil type. Before the models can be applied, it is necessary to conduct simple erosion experiments and evaluate the constants for each soil type under consideration. Once experimental data are available from a range of soil types, the constants for untested, but similar, soils (or an area under study) can be approximated.

Meteorology

As with erosion processes, models designed to predict meteorological conditions can be founded on first principles or can be simply descriptive of the processes observed. Most of the emphasis in micrometeorology in ecology has been directed toward energy balance models which can be used only to predict or to describe the energy budget of relatively simple ecosystems. Information on surface absorptivities and emissivities of the many surfaces present is required. However, these models are limited in scope and at present hold little promise of application to water pollution problems.

Aquatic or Marine Ecosystems

The most commonly used models of aquatic ecosystems are based on mass and energy flow from the lower to higher trophic levels of the system. A typical aquatic model might require data concerning aquatic plants (as the first trophic level involved in fixing radiant energy), benthic organisms, herbivores, and at least one level of carnivores.

Typically, these models require information on the rate of transfer of energy from one level to the next. Rates may depend on several factors, including the biomass available at other trophic levels and constants characteristic of feeding rates, reproduction, mortality, etc. Of the models discussed in this report, this type requires the largest investment of time and effort, and the widest range of specialists, to obtain the data necessary to characterize a particular aquatic or marine ecosystem. Collection of the data must be by specialists and relate to the specific requirements of the model.

Plant Competition

Models that could be used to predict the rate of revegetation of forested areas subjected to logging would be of enormous value for predicting erosion rates, stream sedimentation and the concentration of organic pollutants in surface waters. Unfortunately, a limited amount of research has been conducted in this area. They are mentioned here only as a type of model that may be available in the future.

IMPACT MONITORING

Since this report concerns the prevention of water pollution, the after-the-fact monitoring considerations are of secondary importance and will not be dealt with in detail. A brief discussion is presented, however, because of the significant value for future planning of field data concerning the cause-effect relationships between actual logging operations and water quality in a given subregion. Such information is invaluable, particularly if the individuals responsible for data collection and analysis coordinate closely with the foresters and engineers in the field and the planners responsible for future prescriptions.

Monitoring the water quality or aquatic life impact of silvicultural practices presents a complex array of problems which are usually best assigned to specialists. This would include biologists of various types, hydrologists and water quality specialists. The parameters that lend themselves most to routine monitoring include temperature, turbidity and suspended solids, dissolved oxygen and specific conductance. Analysis of biological properties such as coliform or dissolved organic and inorganic chemicals usually requires sophisticated instrumentation and specific sample handling methods.

Detection of the impact of silvicultural practices is generally evaluated by sampling upstream and downstream from the activity to be monitored. If it is reasonably certain that the parameters measured should be unaffected through that reach of the stream, except by the monitored activity, then samples so compared should be useful. Base level monitoring, before the activity begins, is necessary. Inflow conditions, travel time, stream-channel characteristics, and biologic conditions affect the location, frequency and type of sampling.

Water Temperature

Water temperature can be measured to establish the effects of canopy removal which would reduce shading or increase the solar loading on the small streams. Sampling location should be shaded so solar radiation does not affect reading of the sensor. Maximum and minimum temperatures are important along with the duration of the exposure, particularly for maximum temperatures.

Suspended Sediment

The measurement of suspended sediment is useful in determining the impact of silvicultural practices on the physical condition of the stream. There is a stratification within the stream with larger materials near the bottom and smaller materials near the surface. Consequently, depth-integrated samples are usually taken for most accurate results. Bed load data may also be useful, but involves more complex instrumentation.

Dissolved Oxygen

Organic debris that ends up in the stream channel as a result of timber-felling or yarding can consume dissolved oxygen in the decomposition process. Several portable meters are available for field measurement of dissolved oxygen.

Dissolved oxygen is also a function of water temperature, so both parameters should be measured. Low temperature water usually maintains a higher oxygen concentration than warmer water. The most critical period for dissolved oxygen is during warm summer months when biological activity is high and water temperatures are also high.

Specific Conductance

Specific conductance is a measure of the electric current carrying capacity of water. Increasing values of specific conductance indicate an increasing load of dissolved ions; low values of specific conductance generally indicate very clean, pure water.

Specific conductance meters must be calibrated using standard solutions for the approximate range of values of the stream water in question. It is corrected to a standard temperature of 25°C, usually internally within the meter.

Predicting Effects

BACKGROUND

Predicting the water quality related effects of a timber harvest activity can take various forms. The simplest approach might involve comparing research information applicable to the area (as has been summarized in the previous section "Impact of Forest Practices on Water Quality") with the various facets of the proposed project. The most sophisticated method would involve the use of specific "models" or "equations," which mathematically approximate the processes anticipated (e.g., erosion/sedimentation). Such models serve at least two purposes: (1) they facilitate a better understanding of the process involved, and (2) they are useful in predicting the impacts of a given practice or operation, provided the development, adaptation and use are reasonably correct, and the input data is sufficient (data needs have been previously discussed). Many such models have been programmed for computer application, which allows rapid comparison between various management assumptions.

The models available vary in their usefulness as predictive tools, but many are presently suited for such use. Regardless of their limitations computer models, which incorporate current knowledge of a particular phenomenon, should give results at least as good as the alternative analysis methods that depend on the same data and knowledge of relationships. The value of the computer models is in the rapidity with which results can be obtained. However, in many circumstances, experienced field personnel, sensitive to water quality, and knowledgeable of the specific study area, can accurately "project" the impacts of a range of forest activities. The value of such capability should not be underestimated.

Methods for predicting the effect of forest practices on various environmental factors are applicable to water quality, aquatic ecosystem analysis, growth rates expected given certain stand and environmental variables, and the influence of various levels of fire intensity on site productivity. All prediction methods being used or developed have the same essential character -- given a set of conditions, a prediction may be made, with some degree of certainty, about the effect of specific practices.

One of the first prediction methods used was that of statistical analysis which provided the basis for some of the earliest models used. Multiple regression has been used extensively to predict the influence of several independent variables on a single dependent variable; for example, the effect of soil nutrients, soil moisture and temperature on tree growth.

Over the years, many deterministic models have also been used in forestry. Prediction of the board or cubic foot volume of a tree is based on a geometric model of log size and shape.

These are but a few examples of two broad classes of models which have been, and will continue to be, used for predictive purposes in forestry.

The rapid increase in the use of models has led to some confusion in concepts and terminology. The term "model" is often thought to mean "computer model." To others, "model" implies a geometric representation of a particular object or system. Still others speak of "flow models," which trace the movement of information through an organization, or material through a set of processes. It is noted that to many the term "model" implies a mathematical equation.

"Simulation models," frequently but not necessarily used in conjunction with a computer, are designed to simulate or mimic a particular phenomenon. Many phenomena are of such complexity as to defy the straightforward application of mathematics. In such instances, computer simulation is adopted.

The most critical step in the application of modeling is comparing the model prediction with the behavior of the real system, sometimes called verification. Modeling has been justified on occasion for the clarity and definitive it can bring to a problem, but the test of any model is its predictive capability. Model precision is governed by many aspects of the total process, including available data, the precision of relationships between variables, and the degree to which the problem can be defined. Several models of both a stochastic and deterministic nature are described in subsequent sections. For the most part, these models are expressed in deterministic form. It is emphasized that many of the parameters included in equations are determined by the conditions of specific forest sites.

SOIL EROSION

The prediction of soil erosion involves a complex interaction of variables; consequently, the development of models for analysis is difficult. Wooldridge (1970) has urged caution in the use of such models :

> ...frequently their greatest value is in the manipulation of the various factors to see if they give realistic estimation for soil loss and relationships between factors.

However, in many situations such models, if available and applied correctly, can be useful for prediction.

Smith and Wischmeier (1962) have developed an equation to predict the average soil loss in tons per acre. Although this equation is primarily intended for agricultural land, it provides insight into the soil erosion process and may, upon modification, be useful for predicting erosion for bare soils resulting from logging road construction or vegetation removal.

Another expression of soil erosion similar to the Wischmeier equation was developed earlier by Musgrave (1947). At this time, the Musgrave equation has not been adapted for use in the west. Dissmeyer (1971) developed an equation to evaluate the effect of disturbance on suspended sediments and surface water, and alternative methods for reducing erosion and sedimentation. This method, the "First Approximation of Suspended

Sediment" (FASS) has been used primarily in the southeast and considers gully and channel erosion.

Megahan Erosion Model

A model, or equation, has been developed by Megahan (1974b) that may be used to predict surface erosion (not mass erosion) from watersheds which have experienced roading and logging. A negative exponential equation containing three parameters was derived to describe time trends in surface erosion on severely disturbed soils (primarily the road system). This "model" is most appropriate on Idaho Batholith soils, and is presented as equation 1.

$$E_t = E_n t - S_0(e^{-kt}-1) \qquad 1.$$

E_t = the total erosion since disturbance (tons/mi^2)
E_n = the erosion rate to be expected after a long period, assuming no major disturbance; this value is an estimate of the long-term norm for the site (tons/mi^{-2} day^{-1})
S_0 = the amount of material available to be eroded at time zero after disturbance (tons/mi^2)
k = an index of the rate of decline of erosion following disturbance; this can be thought of as an index of the recovery potential for the site in question (day^{-1})
t = days of elapsed time since disturbance

Data from four different studies of surface erosion on roads constructed from the granitic materials found in the Idaho Batholith were used by Megahan to develop the equation parameters. Two of these studies, Deep Creek and Silver Creek, involve erosion from the entire road prism (cut slopes + roadbed + fill slopes). The other two studies, in the Bogus Basin and Deadwood River areas, were located on doublelane forest roads and designed to measure erosion on road fill slopes only. Plotted data from these studies were used to determine E_n, S_0, and k. The long-term erosion rate (E_n) determined in the Deep Creek data was validated by comparison with average sediment yields for Ditch Creek in the Silver Creek study area.

It was found that the erosion rate for undisturbed lands on the Idaho Batholith averages about 0.07 ton/mile^2/day. For the first year after disturbance, erosion rates per unit of area involved in road construction were three orders of magnitude greater than those on similar undisturbed land, and after almost forty years they are still one order of magnitude greater. According to Megahan, "The potential for damage by such accelerated erosion should be apparent." The study found that, "By far the largest percentage of soil loss occurs within one to two years after disturbance." And that, "Erosion control measures must be applied immediately after disturbance to be effective."

Rainfall intensity data were used to illustrate that variations in erosion forces, as indexed by a rainfall kinetic energy times the maximum 30-minute rainfall intensity, "the erodibility index," were not the cause of the time trends in surface erosion. Although vegetation growth can be an important factor in reducing accelerated erosion, it did not cause the rapid erosion decreases found in the cases studied. The evidence suggests that surface armoring was a dominant factor causing the time trends in surface erosion. The significance of time trends in surface erosion is discussed in the paper.

Other studies, including those by Anderson (1972) and Frederickson

(1970b), have found decreasing time trends in sediment from poorly logged areas in California and in Oregon, respectively.

The Megahan equation is a tool that, with refinement and adaptation to specific sites, has significant potential for estimating soil losses from roading and logging systems proposed on the Idaho Batholith, or other similar erodible soils, primarily in subregions 8, 9, 10, 11, 12 and 13. The principles and methods used in developing the equation have applicability to varying degrees on erodible soils throughout the northwest. It does require field data from logged areas of a similar character in order to determine the basic parameters of the soil/hydrologic zone in question.

WATER TEMPERATURE

Increases in stream water temperature are caused primarily by increased exposure of the stream to direct solar radiation as a result of removing stream side vegetation (Brown 1966, Brown and Krygier 1967, and Brown 1970a). Shade removal may increase radiation loads by six to seven times (Brown 1970). Air temperature and the cooling effects of evaporation are much less important than solar radiation in controlling temperature on small, unshaded streams. Brown (1970) found in western Oregon that solar radiation accounted for over 95 percent of the heat input during the midday period in midsummer.

Several silvicultural practices can change or influence the non-climatic factors which affect the amount of heat received at the stream surface. These factors include:

1) vegetation

2) topography

3) stream channel characteristics

4) inflow of surface and groundwater

5) area, depth and velocity of the stream

Stream side shade is the most important factor influencing changes in water temperature over which the land manager has some control. By maintaining vegetative cover of such height and density as to adequately shade the stream during periods of maximum solar radiation, water temperature increases can be prevented and/or minimized as necessary to meet management goals. The replacement of vegetation after clearcutting along streams may be an acceptable means of rapidly reestablishing vegetation that could adequately provide shade protection and thereby reduce increased stream temperatures. Another approach to reducing the impact of clearcutting along stream sides and the resultant changes in temperature could be accomplished through predicting what temperature changes might occur by regulating the silvicultural system and the size of cutting units.

Brown (1966, 1969) has developed a technique (using an energy budget) for predicting temperature changes of small streams once the stream side vegetation has been removed. This technique is only briefly described in this report. The general equation for the energy budget takes the form, Brown (1969):

$$\Delta S = Q_{NR} \pm Q_E \pm Q_C \pm Q_H \pm Q_A$$

where ΔS = net change in energy stored
Q_{NR} = net thermal radiation flux
Q_E = evaporative flux
Q_C = conductive flux
Q_H = convective flux
Q_A = advective flux

The sign is positive for energy added to the stream and negative for energy losses. The budget techniques used for temperature prediction evaluate the net change in the energy level of the stream (ΔS). Net thermal radiation is the difference between total incoming and total outgoing all-wave thermal radiation. This flux can be measured directly with a net radiometer.

The predicted water temperature change is then a function of the heat applied and the volume of water heated.

$$T_W = \frac{A \times \Delta S}{F} \times 0.000267$$

where T_W = predicted temperature change ($^{\circ}$F)
ΔS = change in energy storage (Btu/ft^2 min^{-1})
A = surface area of study section (ft^2)
F = discharge (cfs)
0.000267 = constant converting discharge from cfs to pounds of water per minute

On unshaded stretches, net all-wave radiation is the predominant energy source during the day; evaporation and convection account for less than 10 percent of the total energy change. Conduction of heat into the stream bottom is an important energy balance component only on shallow streams having a bedrock bottom. Up to 25 percent of the energy absorbed by such a stream is transferred into the bed. Therefore, the maximum daily stream water increase is estimated by:

$$\Delta S = Q_{NR}$$
$$\Delta T = \frac{A \times \Delta S}{F} \times 0.000267$$

The above equation can be used to predict what temperature increase might occur on the site. The impact that such increases can have downstream is predicted by the following mixing ratio formula (Brown 1970a):

$$T = \frac{D_m T_m + D_t T_t}{D_m + D_t}$$

where T = temperature of the main stem after the tributary enters
D_m = discharge of main stem before tributary enters
D_t = discharge of tributary
T_m = temperature of main stem before tributary enters
T_t = temperature of tributary

Brown's technique would have general applicability wherever temperature increases due to vegetation removal along streams are a potential problem. It was developed in western Oregon and has its greatest potential applicability in subregions 3, 4, 5, 6 and 7.

PEAK FLOW ACCENTUATION AND CHANNEL EROSION

The U. S. Forest Service, Region 1, has developed a procedure (water yield increase analysis procedure) for predicting increases in water yield and peak flows due to timber management (or vegetation manipulation). The procedure includes methods for locating, sizing and phasing timber management activities to assure that the percentage of flow increase remains within acceptable limits as determined by channel stability and soil erosion hazards.

This procedure is explained in "Forest Hydrology: Part II, Hydrologic Effects of Vegetation Manipulation," U.S.D.A. Forest Service, and is summarized as follows:

1) Determination of the normal annual runoff for the subject watershed from SCS and USGS information.
2) Determination of the allowable increase limits for annual

yield and periods of maximum channel impact peak flows as affected by (a) soil erosion hazard ratings, (b) stream channel stability, (c) on-site analyses (stream bed inspection), and (d) average annual peak flow patterns and departures.

3) Synthesization of the water yield, peak flows and channel impact periods due to actual or potential vegetation manipulation operations. Such water yield and hydrograph changes are affected by: (a) equivalent clearcut areas and locations, (b) evapotranspiration changes, (c) redistribution of snow accumulation patterns due to timber management activities, and (d) changes in interception patterns.

4) Synchronization of proposed harvest patterns, locations and phasing in order to stay within the accepted yield and peak flow limitations.

The guidelines, curves and functions (which must be developed for each individual watershed) are based on the following:

1) geology
2) soil erosion hazards
3) mean annual runoff
4) stream order
5) hydrologic recovery rate
6) stream channel stability
7) hydrologic response
8) type of vegetation manipulation
9) past use or abuse by man
10) wildfire and flood history

In proposing a matrix evaluation format, the publication lists the following information needs: watershed size, soil types, soil mass failure hazard, soil surface erosion hazard, geologic type, drainage pattern, mean slope, habitat type, commercial timber type, channel stability, stream order, basin orientation, stream gradient, on-site water use, off-site water use, past watershed natural activities, past watershed man activities, mean basin elevation, mean basin precipitation, mean basin runoff, hydrologic condition, proposed method of logging and proposed silvicultural treatment. An overall consideration is the conformance to state water quality standards.

The report lists five alternatives for meeting established water yield increase guidelines, as follows:

1) Increase or decrease the area or size of vegetation to be removed
2) Modify the method of removal, i.e., clearcut vs. shelterwood harvest
3) Collect additional soil, geology and hydrology data, i.e., refined input data
4) Modify the harvest by energy slopes to desynchronize the increased water yield
5) Exceed guidelines after inclusion of mitigation such as these measures: (a) sediment basins, (b) road stabilization, (c) debris clearing, (d) bank stabilization, (e) progressive revegetation, (f) high lead logging, etc., (g) buffer strips, (h) channel stabilization, (i) eliminate spring logging, (j) modify method of harvest

The report presents a useful "Stream Reach Inventory and Channel Stability Evaluation" procedure and form which is presented in Tables 12 and 13. The report also goes into detail concerning the calculation of acceptable limits for increases in yields and peak flows, primarily based on channel characteristics and soil/slope information.

These procedures were developed primarily as a part of planning programs for the Nez Perce and Panhandle National Forests. The "Forest Hydrology, Part II" handbook details four variations of the procedure. Currently, there is disagreement concerning the effects of clearcutting on peak flows and channel erosion. Research has shown that water yield and peak flows generally increase in areas of extensive vegetation removal (Rothacher and Glazebrook 1968; Helvey 1972 and Anderson and Hobba 1959). The important question concerns the effect of such increased peak flows on channel erosion. This depends on the specific stream site, but the general significance in the northwest is unknown. However, since the procedure outlined above is directed toward minimizing the impact, if no channel erosion potential exists the procedure would not be used. While the methodology is still in the development stage, the basic approach is sound. The subregional significance needs to be determined, but channel erosion analysis should be included in forest management planning, at least on a planning-unit basis.

AQUATIC OR MARINE ECOSYSTEM MODELING

Numerous models are available for predicting the effects of pollutant discharges on a water body. Most of these models synthesize the

Table 12

Taken From: Forest Hydrology, Part II
USDA Forest Service

R-1 STREAM REACH INVENTORY and CHANNEL STABILITY EVALUATION

LOCATION

Forest Name__________ & No.____ Ranger Dist.__________ Survey Date________

Observer(s)__________ Stream Name__________

Reach Description & Other Identification__________

Aerial Photo No.________ Coordinates & Identification________ P.W.I. W/S No.___ - ___ - ___ - ___ - ___ - ___ - ___

INVENTORY MEASUREMENTS & ESTIMATES*

Stream Size & Discharge Survey Date Width____Ft. Ave.Depth ____Ft. Velocity ____f/s Discharge _____cfs

At Maximum ____Ft.* ____Ft.* ____f/s* _____cfs*

Gradient____% Sinuosity ratio_____ Stream Order_____ Turbidity Level________ Stream Stage________

Channel Flow Pattern__________

Soils Description__________

Landform and/or Geologic Type__________

Vegetative Type__________

Number of debris jams &/or fish blocks/mile_____. Upstream watershed impacts (Types)__________

____

Size Composition of Bottom Materials (Total to 100%)

1. Exposed bedrock............____%
2. Large boulders, 3' + Dia..____%
3. Small boulders, 1-3'......____%
4. Large rubble, 6"-12"......____%
5. Small rubble, 3"-6"......____%
6. Coarse gravel, 1"-3".....____%
7. Fine gravel, 0.1"-1".....____%
8. Sand, silt, clay, muck...____%

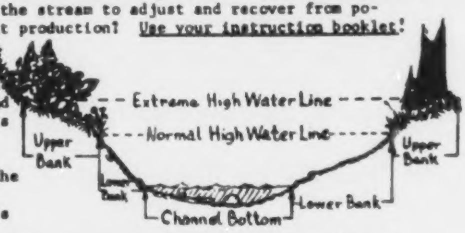
Weather and Other Remarks __________

____

INSTRUCTIONS

Use a separate rating form for each length of stream that appears similar. Complete the inventory items above using maps, aerial photos, and field observations and measurements. On the opposite side of this page, the channel and adjacent flood plain banks are subjectively rated, item by item, following an on-the-ground inspection. Circle only one of the numbers in parentheses for each item rated. If actual conditions fall somewhere between the conditions as described, cross out the number given and below it write in an intermediate value which better expresses the situation. Don't key in on a single indicator or a small group of indicators but use them all for the most diagnostic value. The indicators are interrelated so don't dwell on any one item for long. Do the best you can and the pluses and minuses should balance out. Keep in mind that each item directly or indirectly seeks to answer three basic questions: (1) What are the magnitude of the hydraulic forces at work to detach and transport the various organic and inorganic bank and channel components? (2) How resistent are these components to the recent streamflow forces exerted on them? (3) What is the capacity of the stream to adjust and recover from potential changes in flow volume and/or increases in sediment production? Use your instruction booklet!

DEFINITION OF TERMS AND ILLUSTRATIONS

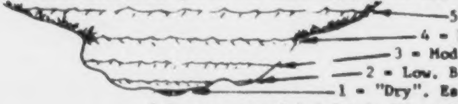


Upper Bank - That portion of the topographic cross section from the break in the general slope of the surrounding land to the normal high water line. Terrestrial plants & animals normally inhabit this area.

Lower Banks - The intermittently submerged portion of the channel cross section from the normal high water line to the water's edge during the summer low flow period.

Channel Bottom - The submerged portion of the channel cross section which is totally an aquatic environment.

Stream Stage - The height of water in the channel at the time of rating is recorded on the top half of this page using numbers 1 through 5. These numbers, as shown below, relate to the surface water elevation relative to the normal high water line. A decimal division should be used to more precisely define conditions, ie. 3.5 means 3/4ths of the channel banks are under water at the time of rating.



5 = Flooding. The flood plain is completely covered.
4 = High. Channel full to the normal high water line.
3 = Moderate. Bottom and ½ of lower banks wetted.
2 = Low. Bottom covered but very little of the lower banks wet.
1 = "Dry". Essentially no flow. Water may stand in bottom depressions.

* Use an asterisk behind all estimates that could be measured but weren't.

Table 13

Taken From: Forest Hydrology, Part II
USDA Forest Service

USDA FOREST SERVICE

R-1 STREAM CHANNEL STABILITY FIELD EVALUATION FORM

Item Rated	Stability Indicators by Classes							
	EXCELLENT		GOOD		FAIR		POOR	
UPPER BANKS								
Landform Slope	Bank slope gradient <30%	(2)	Bank slope gradient 30-40%	(4)	Bank slope gradient 40-60%	(6)	Bank slope gradient 60% +	(8)
Mass Wasting (Existing or Potential)	No evidence of past or potential for future mass wasting into channels.	(3)	Infrequent and/or very small. Mostly healed over. Low future potential.	(6)	Moderate frequency & size, with some raw spots eroded by water during high flows.	(9)	Frequent or large, causing sediment nearly yearlong OR imminent danger of same.	(12)
Debris Jam Potential (Floatable Objects)	Essentially absent from immediate channel area.	(2)	Present but mostly small twigs and limbs.	(4)	Present, volume and size are both increasing.	(6)	Moderate to heavy amounts, predominantly larger sizes.	(8)
Bank Protection from Vegetation	90% + plant density. Vigor and variety suggests a deep, dense root mass.	(3)	70-90% density. Fewer plant species or lower vigor suggests a less dense or deep root mass.	(6)	50-70% density. Lower vigor and still fewer species form a somewhat shallow and discontinuous root mass.	(9)	<50% density plus fewer species & less vigor indicate poor, discontinuous, and shallow root mass.	(12)
LOWER BANKS								
Channel Capacity	Ample for present plus some increases. Peak flows contained. W/D ratio <7.	(1)	Adequate. Overbank flows rare. Width to Depth (W/D) ratio 8-15.	(2)	Barely contains present peaks. Occasional overbank floods. W/D ratio 15-25.	(3)	Inadequate. Overbank flows common. W/D ratio >25.	(4)
Bank Rock Content	65% + with large, anguler boulders 12" + numerous.	(2)	40 to 65%, mostly small boulders to cobble 6-12".	(4)	20 to 40% , with most in the 3-6" diameter class.	(6)	<20% rock fragments of gravel sizes, 1-3" or less.	(8)
Obstructions Flow Deflectors Sediment Traps	Rocks, old logs firmly embedded. Flow pattern of pool & riffles stable without cutting or deposition.	(2)	Some present, causing erosive cross currents and minor pool filling. Obstructions and deflectors newer and less firm.	(4)	Moderately frequent, moderately unstable obstructions & deflectors move with high water causing bank cutting and filling of pools.	(6)	Frequent obstructions and deflectors cause bank erosion yearlong. Sed. traps full, channel migration occuring.	(8)
Cutting	Little or none evident. Infrequent raw banks less than 6" high generally.	(4)	Some, intermittently at outcurves & constrictions. Raw banks may be up to 12".	(8)	Significant. Cuts 12"-24" high. Root mat overhangs and sloughing evident.	(12)	Almost continuous cuts, some over 24" high. Failure of overhangs frequent.	(16)
Deposition	Little or no enlargement of channel or point bars.	(4)	Some new increas in bar formation, most from coarse gravels.	(8)	Moderate deposition of new gravel & coarse sand on old and some new bars.	(12)	Extensive deposits of predominately fine particles. Accelerated bar development.	(16)
BOTTOM								
Rock Angularity	Sharp edges and corners, plane surfaces roughened.	(1)	Rounded corners & edges, surfaces smooth & flat.	(2)	Corners & edges well rounded in two dimensions.	(3)	Well rounded in all dimensions, surfaces smooth.	(4)
Brightness	Surfaces dull, darkened, or stained. Gen. not "bright".	(1)	Mostly dull but may have up to 35% bright surfaces.	(2)	Mixture, 50-50% dull and bright, ± 15%, ie 35-65%.	(3)	Predominately bright, 65% +, exposed or scoured surfaces.	(4)
Consolidation or Particle Packing	Assorted sizes tightly packed and/or overlapping.	(2)	Moderately packed with some overlapping.	(4)	Mostly a loose assortment with no apparent overlap.	(6)	No packing evident. Loose assortment, easily moved.	(8)
Bottom Size Distribution & Percent Stable Materials	No change in sizes evident. Stable materials 80-100%.	(4)	Distribution shift slight. Stable materials 50-80%.	(8)	Moderate change in sizes. Stable materials 20-50%.	(12)	Marked distribution change. Stable materials 0-20%.	(16)
Scouring and Deposition	Less than 5% of the bottom affected by scouring and deposition.	(6)	5-30% affected. Scour at constrictions and where grades steepen. Some deposition in pools.	(12)	30-50% affected. Deposits & scour at obstructions, constrictions, and bends. Some filling of pools.	(18)	More than 50% of the bottom in a state of flux or change nearly yearlong.	(24)
Clinging Aquatic Vegetation (Moss & Algae)	Abundant. Growth largely moss like, dark green, perennial. In swift water too.	(1)	Common. Algal forms in low velocity & pool areas. Moss here too and swifter waters.	(2)	Present but spotty, mostly in backwater areas. Seasonal blooms make rocks slick.	(3)	Perennial types scarce or absent. Yellow-green, short term bloom may be present.	(4)
COLUMN TOTALS →			→		→		→	

Add the values in each column for a total reach score here. (E.____ + G.____ + F.____ + P.____ = ____).

Reach score of: <38=Excellent, 39-76=Good, 77-114= Fair, 115+=Poor.

R1-2500-5 (6/73)

concentration of pollutants at critical locations. For a lake, reservoir or marine environment, these locations may vary by depth and distance from the discharge, or be primarily determined by critical aquatic or marine life areas. For stream environments, the evaluation points are downstream from the pollutant discharge, generally at critical locations such as just above a community water supply or major tributary confluence.

Water quality or aquatic and marine ecosystem models can be very beneficial for predicting the effects of silvicultural practices on water bodies. Through reiterative analysis, alternative land use and management schemes can be evaluated for water quality impact.

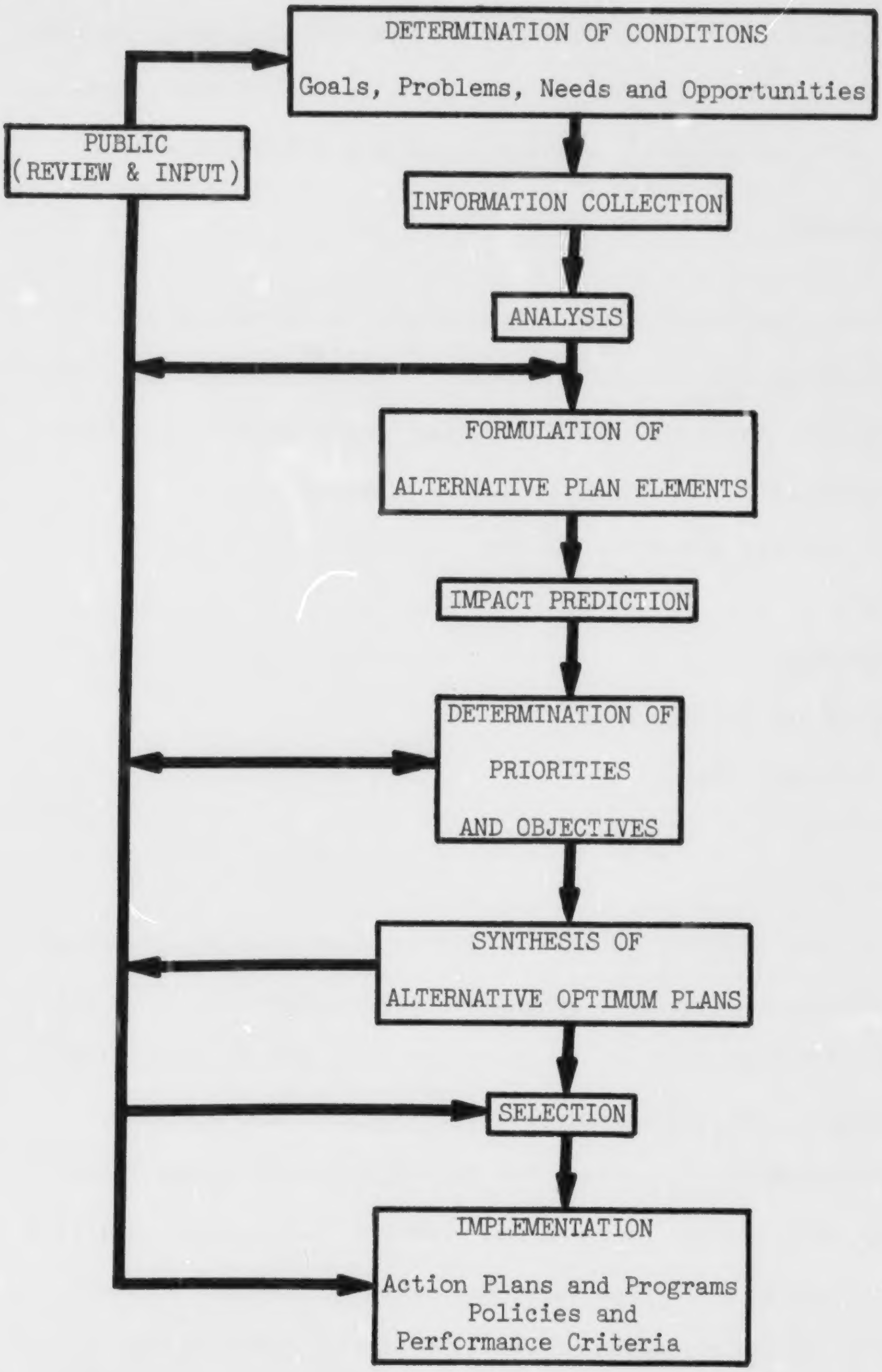
One of the most useful models for stream ecosystems was developed by Chen and Orlob (1972). The data requirements for this model are very specific and the program must be adapted to the particular stream involved. This type model differs from the water quality types in that the biological or aquatic life effects are examined as contrasted to water quality per se. Essentially, the same model is available for lake, reservoir or marine environments.

Planning

Planning is the process of analyzing and evaluating the implications of potential future actions, followed by the selection of a plan that can best realize desired goals. Planning is best summarized as the process of forethought and strategy selection. It must be followed by implementation, meaning the transformation of the plan into action programs, projects and performance criteria. Table 14 illustrates a basic planning methodology,

Table 14

Basic Planning Methodology


DETERMINATION OF CONDITIONS
Goals, Problems, Needs and Opportunities
PUBLIC
(REVIEW & INPUT)
INFORMATION COLLECTION
ANALYSIS
FORMULATION OF
ALTERNATIVE PLAN ELEMENTS
IMPACT PREDICTION
DETERMINATION OF
PRIORITIES
AND OBJECTIVES
SYNTHESIS OF
ALTERNATIVE OPTIMUM PLANS
SELECTION
IMPLEMENTATION
Action Plans and Programs
Policies and
Performance Criteria

which is most applicable to broad-scope public planning programs. However, the same basic method, with greater or less emphasis on different elements, would apply to site (or project) planning on private and public lands.

BASIC METHODOLOGY

Water quality planning on forest lands should be integrated into a comprehensive planning effort and not treated as a separate process. The planners responsible should be interdisciplinary and have the capability to include the following considerations in the planning:

- aquatic biology and water quality
- forestry
- soils/geology
- hydrology and geohydrology
- fisheries and wildlife
- engineering
- economics

In addition, the planning should include consideration of the pertinent federal, state and local laws, ordinances and requirements. For public lands, the most efficient approach to accomplish this may be to utilize interagency planning teams with representatives of fish and wildlife, planning and environmental agencies. For nonpublic lands, formal interagency planning teams may not be feasible. However, the interdisciplinary nature of the effort is still important, and early involvement of state, federal and local regulatory agencies can save time in the long run.

The planning methodology depicted in Table 14 should not be interpreted to imply that all elements of forest land planning must proceed simultaneously through this procedural logic. The basic data required for decision making in certain planning areas may be adequate much earlier than in other areas, and the needs more critical. Most importantly, some types of early decisions do not preclude other important planning options. Once the information base is adequate for these limited-committal decisions, it may be acceptable, and often desirable, to initiate limited action early in the process, provided that proper plan selection procedures are followed. For example, it may be desirable and acceptable to revegetate the critical slope areas within a previously logged watershed before finalization of a comprehensive land use plan due to (a) critical water quality needs for early revegetation, (b) program scheduling needs and early availability of manpower and/or funds, and (c) important management options not being foreclosed by the action.

The following criteria should all be satisfied in order for such early decisions to be advisable:

- other important management/planning options are not precluded (or foreclosed),
- the information base is adequate for the type of decision contemplated, and
- delayed action would result in adverse effects on the basic physical resources involved

An important consideration affecting the desirability of such early decision making would be the availability of financial or manpower resources now, that might not be available at the time of plan finalization.

The planning process must be a continuing program, not only to continue the planning in new geographic areas, but to refine, revise or expand previously made planning decisions in response to new or feedback information. The success of planning and implementation programs should be monitored and evaluated continually.

The following discussion follows the methodology presented in Table 14.

Basic Information and Analysis

The first phases of a forest land use planning process should involve (a) a determination of the conditions which will constrain the planning, (b) the formulation of general goals, and (c) collection and analysis of the information and data pertinent to the study. Some information required for the planning will be available, but additional data may be necessary (refer to the discussion under "Information Requirements").

A preliminary overview of the study area's intrinsic physical/environmental, social and economic qualities is needed to determine the goals, problems, needs and opportunities requiring emphasis. Public involvement is advisable during this phase, which in effect is the first attempt to set the direction of the study.

Alternative Plan Elements

During this phase, the planning study is divided into logically separable elements (e.g., logging method selection), analyzed, and the impact and implications predicted. Such impact prediction should include environmental, social, economic and financial analyses. All such elements and their impacts are interrelated, necessitating a reiterative type of analysis where the effects of one alternative and its mitigation measures are taken into consideration in the analysis of other elements. The number of interrelationships requiring separate analysis, however, can usually be minimized to allow a reasonably simplified analysis procedure. Where this is impossible, computer models, particularly for impact prediction, are valuable if available.

Priorities and Objectives

One of the most important planning phases involves the determination of all the implicit and explicit objectives and priorities of the study. These study "directives" must be understood by the planning team and interested parties external to the planning effort. Public understanding is important if the land involved is public, if public agency approval is required, or if public resources are affected.

For water quality planning, recent national goals and objectives have been established by Congress through the Federal Water Pollution Control Act Amendments of 1972 (Public Law 92-500). In addition, all states have enacted legislation that defines water quality requirements. Additional requirements have been set through laws and regulations administered by federal or state forest resource agencies. Many local land use (planning and zoning) agencies also have water quality goals or programs. These local water quality requirements are generally embodied in local ordinances which are legally binding on private, state and federal lands (P.L. 92-500, Section 313).

Goals, and the more specific objectives, should be outlined for each land unit according to its characteristics and values in addition to the goals mandated by federal, state and local laws. Throughout the planning process, choices and tradeoffs will be made according to value judgments by the planning team. The criteria for choosing one alternative over another should be explicit and formulated early in the process.

Synthesis

Once the potential elements of the final plan and the implications are understood, alternative plans can be formulated, based on the alternative plan elements previously analyzed. Such alternative plans should represent a range of methods to achieve various (possibly conflicting) goals. Examples of such goals include resource conservation, regional development, national economic stability, private economics and environmental quality.

Selection

Once the alternative plans are examined, a selection can be made. The final plan may be one of the alternatives examined, or a combination of parts of various plans. The examination of alternatives can serve to stimulate thinking on entirely new approaches.

Implementation

Planning is no more than the means to an end -- the initiation of efficient, effective programs, projects or policies. Plan implementation can involve, for example, broad or specific policies for guiding forest management decisions, action plans such as a watershed rehabilitation plan, financial or funding programs, and performance criteria by which to judge the logging methods used within the project area.

Public Involvement

Informing the interested public, and public agencies, throughout the planning effort and encouraging their comments and involvement is beneficial, and for public lands, necessary. In this way, individuals (or agencies) are given the opportunity to express their values and concerns and the planning process is strengthened through early exposure to criticism and a broad spectrum of information. In the case of private lands the need is often different, however, the involvement of the public through various public agencies is usually required.

SITE SPECIFIC PLANNING

The "Basic Planning Methodology" shown as Table 14 has numerous variations, including methods more applicable to small private forest units or specific projects (site specific planning). The basic planning logic should be similar, but differ in the emphasis placed in each element. The following describes the major potential differences:

a) public input would probably be limited to the necessary public agency approvals (for private lands),

b) the basic goals on private lands would cover a more narrow range, with emphasis on economics,

c) alternative plan (and plan element) formulation would be minimized, and

d) the "planning team" may consist of a forestry consultant only (on small private land ownerships)

The basic need is for information review, including laws and regulations, with an examination of alternatives before finalizing the plan or project. Specialized information is required of the type and sources listed in Table 9.

Sensitive Areas and Facilities Location

Planning is the most important key to preventing water pollution from timber harvesting, residue management and reforestation. The most important consideration in such planning is avoiding or minimizing the soil and vegetation disturbances on or affecting sensitive areas.

Such areas include:

- stream channels
- stream banks and water influence environs
- marine, lake or reservoir environments
- steep slopes or unstable soils

A complementary and equally important planning objective is the location of facilities and layout of logging systems in a manner that not only avoids and protects sensitive areas, but capitalizes on land that is (1) the most stable, and (2) has a minimum potential for producing water pollution impacts.

STREAM CHANNELS

Summary

Based on the available information, the following criteria for stream channels would protect the quality of waters on, or affected by, timber harvest areas:

- Utilize experienced fisheries management specialists and State Fish and Game Department personnel to determine (1) the importance of the stream for fisheries and water quality, and (2) special management requirements for stream channel protection.

- Remove all debris and residue attributable to timber harvesting from below the high water level, except where such debris will definitely improve stream channel structure.
- Avoid using construction equipment or skidding logs in or across streambeds; yard across streams only if logs are fully suspended above the stream channel.
- Fell and limb trees away from all streams and watercourses.
- Avoid channel alterations.
- Avoid locating landings, slash piles and other facilities or residuals within any watercourse.
- For stream channels or watercourses in which flow is intermittent and fish spawning or rearing is negligible:
  - a) remove slash and other timber harvest debris below the high water level
  - b) hold surface disturbance to a minimum
  - c) minimize the operation of logging and construction equipment below the high water level and allow such operation only during no-flow periods and if down stream fisheries will not be affected.
- Obtain written concurrence for a specific plan from state water rights, fisheries and environmental agencies before diverting water from, or altering, any stream.
- Provide for the protection and maintenance of stream side vegetation (as discussed later).

Discussion

In addressing the question of guidelines for applying forest practice rules relating to Class II streams in the Northwest Forest Region of Oregon (streams of little or no value for fish spawning or rearing, but which affect downstream water quality), the Oregon Department of Forestry concluded the following:

1. Positive preventive measures must be taken to keep the material out of streams.
2. The greatest concern is the potential for 'sluice-outs' which could carry material to Class I streams.
3. Stream clearance requirements can be relaxed where:
   a. there is no 'sluice-out' potential,
   b. 'sluice-outs' cannot reach Class I Streams.
4. Due to steeper gradients, low flows and narrow canyons characterizing Class II streams, water quality problems, particularly with regard to dissolved oxygen and temperature, appear to be minimal.
5. Where cleanup is required, it should be done in a manner least likely to create undesirable disturbance.
6. Presence of slash in streams can have a beneficial effect on some streams, through the sediment trapping and shading capabilities.

THE FOLLOWING GUIDELINE IS INTENDED TO AMPLIFY THE ABOVE POINTS:

Positive Preventive Measures

1) Trees should be felled away from Class II streams whenever possible. Improper felling practice is probably the greatest single contributor to debris in Class II streams. Because of the usual time lag between felling and yarding, limbs and tops which fall into streams may cause damage to water quality which persists even after yarding.

2) When it can be done, trees which do fall into streams should be yarded out at least to a point above the high water level before removing limbs and tops. Fine material such as needles has a greater effect on dissolved oxygen than does larger material.

3) Avoid yarding across Class II streams where possible, to minimize disturbance of the bed and banks.

One of the most comprehensive assemblies of guidelines for stream channel protection is being applied by the U. S. Forest Service Intermountain and Northern Regions. Portions of these criteria are mitigative measures and a selected few are listed for cases where some stream alteration or disturbance is unavoidable.

> Where channel changes are deemed necessary, natural channel velocities shall not be increased in the affected stream reach. This will be assured by installing drop structures, by constructing acceptable meanders, or by other approved methods. Where drop structures are installed they shall be designed to permit fish passage, if this is an established occurrence.
>
> Construction and other activities affecting channels above spawning areas shall be deferred if they will adversely affect eggs or alevins in the gravel.
>
> During construction and other activities affecting channels, areas containing anadromous fish redds shall be protected.
>
> When channel changes or alterations are the best alternative, mitigating measures shall be provided to foster replacement of the aquatic habitat to as near natural condition as is possible.
>
> When channel changes are unavoidable, new channels shall be completed, including scour and erosion protection, before turning water into them.
>
> Log landings shall not be located adjacent to stream channels or on areas where surface runoff will discharge directly into the channel.

Construction shall be avoided during wet season or other undesirable runoff periods to minimize sedimentation directly into streams. If construction is essential during such periods, sedimentation damage will be minimized by installing debris basins or using other methods to trap sediment.

STREAM BANKS AND WATER INFLUENCE ENVIRONS

Summary

One of the most important forest land areas to protect for water quality purposes is the land adjacent to streams and watercourses. The values of stream-side vegetation for various considerations has been discussed throughout Chapter 4. In summary, retaining vegetation and minimizing soil disturbance in such zones can significantly reduce water quality impacts by:

- retention of stream shading and temperature regimes favorable to salmonid fisheries
- minimization of drop impact, soil particle entrainment and subsequent sedimentation from the zone immediately adjacent to the stream during periods of high flow or intense rainfall
- interception and deposition of sediment, particularly the larger particles, in the small rivulets resulting from major storms
- reducing the risk of channel damage due to equipment operation, skidding and slash piling in the stream
- aiding in the control and interception of debris

Based on the information available, the minimum buffer zone widths (one-side) for protecting water quality would generally fall within the following range, depending on site characteristics, water quality standards, fishery to be protected and streamflow:

1.	Major perennial streams	40' - 200'
2.	Minor perennial streams	20' - 50'
3.	Important intermittent streams	10' - 30'

For discussion purposes, major perennial streams are defined as those which flow year-round and have a minimum flow generally greater than 3 cfs. Minor perennial streams are defined as those which flow year-round and have a minimum flow generally less than 3 cfs. Important intermittent streams are defined as those which do not always flow year-round, but which may be important for water quality downstream or in some phase of fish rearing.

In most cases the optimum width will vary considerably along the length of a stream, and generally be greater than the minimum. Considerations in the determination of buffer zones include the following:

1) For temperature control the timber volume retained is relatively unimportant. The important factors are angular canopy density and shade provided. (See Brazier and Brown 1973.)

2) Some intermittent streams have been found to be important for fish rearing (for Alaska see USDA Forest Service et al n.d.).

3) Site conditions immediately adjacent to the stream (e.g., slope) are particularly important when sediment interception is an objective (see Trimble and Sartz 1957).

4) The water quality values of buffer zones vary in significance from stream to stream.

5) Selection cutting with minimum disturbance logging may offer sedimentation values of similar or greater water quality value than buffer zones with clearcutting and high disturbance logging (Lantz 1971, Hornbeck 1967, Reinhart 1964).

Discussion

The question of "buffer zones" or "leave strips" has frequently been discussed and examined by both researchers and practitioners, particularly during the past five years. It must be stressed that this report deals with such zones only insofar as they contribute to the protection of water quality. Other important forest management goals, e.g., wildlife protection, may also require the retention of the vegetation adjacent to streams. Such requirements will not always coincide with the water quality requirements for buffer zones. The primary point is that there are multiple needs for maintaining vegetation along streams that should be analyzed separately and then synthesized.

Some minimum requirements for buffer zones along spawning and rearing streams are advisable in the subregions covered by this report. However, such requirements may vary considerably from one subregion, or stream, to another because of differences in topography, hydrology, meteorology, silvicultural practices, soils, fisheries and geology. In one subregion the primary objective may be to protect against temperature increases, while in another, erosion and sedimentation may be most important.

The ideal approach involves minimum requirements, based on a range of stream classifications, that are subject to enlargement or optimization through comprehensive interdisciplinary planning on a stream-by-stream basis. The objectives of such planning and revision should be to achieve a level of water quality protection that (1) adequately protects the fishery, (2) meets state and federal water quality requirements, and (3) provides an equal or greater protection than the minimum specified. With this procedure, the differences in stream use and classification can be recognized.

Different conclusions have been reached concerning the best approach to determine buffer zone widths. Some have warned against the setting of blanket optimum or minimum widths (Narber, Mason and Mundy 1973, Streeby 1970). Others have recommended such optimum or minimum widths (FWPCA 1970, Anderson 1973, Jones and Stokes 1972).

It has been suggested by Trimball and Sartz (1957) that a logging road filter strip should be a minimum of "25 feet plus 2 feet for each one percent of slope between stream and road." A curve was prepared showing the relationship between degree of slope and the distance sediment is carried by storm runoff.

Of major importance is the varying significance of temperature increases and sediment interception from one subregion to another. In the Idaho Batholith (Intermountain and Northern Idaho subregions), sediment interception by buffer strips has been found to be important (Haupt and Kidd 1965). Due to the generally low water temperatures in these mountainous areas, stream side vegetation for temperature control is probably of less importance than in western Oregon.

It has been concluded by Brown (1972) that,

> "One popular alternative (for minimizing sedimentation) is a strip of vegetation between the road or harvest area boundary and the stream. Such a strip is often called a buffer strip. A "no-entry" zone is an excellent technique for protecting channel banks and the stream bed during logging. But such a technique is of little value in handling erosion from side slopes above the buffer in most of the mountainous West. Vegetative filtration of soil materials borne in runoff water by a buffer strip assumes that sheet flow similar to that occurring on eastern agricultural soils is the predominant erosion mechanism. In most forest watersheds, the highly dissected topography and rough surface precludes such flow. Water quickly finds its way into rills or channels. These converge to form larger channels. Since channel flow predominates eroded materials are carried through a buffer strip."

Buffer zones offer protection from channel and surface erosion in the area immediately adjacent to streams. They also intercept the sediment in the small rills and rivulets which originate just above the buffer strip. Large flows would not be significantly affected by buffer strips and such sedimentation would have to be controlled by other means.

MARINE, LAKE OR RESERVOIR ENVIRONMENTS

Summary

The management for water quality purposes of estuaries, lakes or reservoirs and the adjacent land and vegetation has not been the subject of extensive research. Such shoreline management has most often been practiced for esthetic, wildlife or recreational purposes rather than water quality per se.

While the importance of shoreline protection to water quality is apparently greater for small to medium-sized streams than for estuaries, lakes or reservoirs, this general rule can be expected to have exceptions. Small fresh- or salt-water bodies, particularly shallow spawning or rearing areas, can present a high potential for water quality degradation. This depends on:

- exposure
- normal temperature regime
- hydraulic characteristics (flushing)
- soil/slope characteristics
- relative amount of the sensitive area affected

For example, a shallow, narrow estuarine area normally provided with shade by tall trees along a steep, erodible shoreline to the south could be subjected to dramatic thermal and sedimentation impacts if the vegetation is removed and the soil extensively disturbed. If such an area is an important rearing area for fish, the biological impacts could be severe. Since such areas are generally less active hydraulically than streams, under certain conditions the potential for adverse effects could be greater.

The following would tend to minimize the adverse effects of timber harvesting and transport activities on the water quality of marine, lake or reservoir environments:

- locate the important aquatic or marine habitat areas early in the planning
- determine the width of vegetation needed as a "buffer zone"

- use dry land storage and barging of logs whenever possible. If storage in marine or fresh waters is required, minimize the number of sites and the volume of logs (and time period) stored
- avoid activity in the vicinity of important habitat areas, bays and intertidal or shallow areas

Discussion

The U. S. Forest Service proposed the following three guidelines for the Southern Chilkat Study Area, Tongass National Forest, which exerts a significant influence on a productive marine environment:

- Consult a biologist prior to any developmental action along the shoreline and estuarine areas.
- Give preference to dryland storage and barging in any logging activity.
- Exclude any timber harvest within approximately a one-fourth mile fringe of the shoreline except for salvage of blowdown, insect, disease, or fire damaged timber.

The National Marine Fisheries Service (NOAA), Juneau, Alaska, has recommended the following to reduce the adverse impact of fisheries from log dumps and raft storage areas:

1. Maximize the distance between the mouths and intertidal channels of anadromous fish streams and the sites.
2. Maximize the distance between tide flats and subtidal beds of aquatic vegetation and the sites.

3. Use the steepest shores having the least intertidal subtidal zone.

4. Minimize disturbance of the shoreline as a result of clearing, road building and other activities that might produce silt or otherwise disrupt the estuarine environment.

5. Minimize storage time for rafted logs before transport to the mill.

6. Minimize the number of active dump sites and log storage areas in any given bay or bay complex.

7. Minimize the filling of intertidal and subtidal areas for the construction of log dumps, fuel transfer facilities, equipment loading ramps, etc.

8. Minimize the use of intertidal areas as a source of borrow.

9. Minimize interference with other established uses such as commercial and sport fishing, hunting and anchorages for commercial and recreational boats.

10. Whenever possible locate sites outside bays, along straits and channels.

11. Locate dump sites in deep bays rather than in shallow bays. Select bays without sills or other natural restrictions to tidal exchange.

12. Locate dump site near mouths of bays rather than at heads of bays unless the environment at the mouth of the particular bay in question has some special significance.

13. Use the deepest water possible for booming grounds and log raft storage areas.

14. Select sites that accomodate future timber development without requiring continual relocation.

Recommendations on storage, handling and transportation of logs on public waters were made by the Industrial Forestry Association (1971) as follows:

1. Logs should be put into water by easy let-down means.

2. Logs should be bundled before being put into public water where the log flow pattern of the operation makes it practical to

accomplish log handling including sorting logs by species, grade, use and specific destination prior to the time the logs are put into the water.

3. Accumulations of bark and other debris from the land phase of log handling of log dumps or mill sites should be kept out of the water.
4. Keep the volume of logs stored in water and length of storage at a minimum.

STEEP SLOPES AND UNSTABLE SOILS

Summary

Areas of steep slopes (those generally in excess of 50%, see Table 15), or unstable soils present potential water quality problems that are best avoided whenever possible. The most advantageous approach involves identifying the sensitive soil and slope areas and allocating them to low disturbance uses. It is advisable to avoid road construction and minimize timber harvest in such areas. Information pertinent to the study of erosion and sensitive soils as affecting water quality can be found in Chapter 4.

The following summarizes the water quality protection criteria for timber harvest, logging, residue management and reforestation:

- o A land systems management plan, including programs for minimizing soil loss, erosion and mass soil failure, should be developed for all forest land units by experienced soil scientists, hydrologists and geologists.
- o Avoid skidding in ravines or V-notches.
- o Limb logs before yarding if they are to be ground-skidded.
- o Apply zone-sensitive saturation (max/min) and slope limits to each type of logging used, particularly tractor logging.

- Minimize soil disturbance through the use of aerial logging methods such as skyline, running skyline, helicopter or balloon systems in steep-sloped or unstable soil zones (e.g., the Idaho Batholith).
- Consider the use of slash for soil protection purposes.
- Consider limiting logging to periods when snow cover can provide protection to the soil and understory.

Discussion

In a report concerning the California Forest Protective Law, Jones and Stokes Associates, Inc., has proposed certain standards to the Watershed Conservation Board that pertain to critical areas and the location of facilities as follows:

> The Board shall set permissible soil loss levels for the district areas.
>
> The Board shall monitor logging operations and shall report individual and cumulative soil losses attributable to logging.
>
> Permittee shall include an erosion control program in each logging plan describing in detail the facilities and techniques used to keep soil losses at permissible levels.
>
> Permittee shall pay the cost of erosion monitoring.

The U.S. Forest Service and Alaska Departments of Fish and Game and Natural Resources (n.d.) have outlined criteria for minimizing erosion and sedimentation from steep slopes or unstable soil areas (included with other fish habitat protection criteria).

The Oregon office of the Soil Conservation Service prepared a paper entitled "Agronomy Practices Standards and Specifications for Critical

Area Planting." These standards can be applied to an area of surface disturbance with some modification for each site.

W.J. Kidd, U.S. Forest Service, in studies on the Idaho Batholith, summarized his research on 569 intervals of 105 logging skidtrails as follows:

1. Erosion is greater and rate of healing is slower on soil derived from granite than on soil from basalt.
2. More soil is eroded from skidtrails unavoidably located in ravine bottoms than from trails on sidehills.
3. Control structures that divert water off the skidtrail onto undisturbed forest floors are superior to those that only retard water movement and filter out sediment along the skidtrail.
4. Any increase in spacing between control structures is accompanied by increase in soil movement.
5. Optimum spacing between erosion control structures depends on the percent of slope, whether location of the skidtrail is on a sidehill or in a ravine, and the soil parent material.

Kidd concluded that proper treatment of bared skidtrails after logging reduces the hazard of potential erosion. He also concluded that all types of erosion control structures on skidtrails were generally ineffective in ravine bottoms. Water diverting structures (log water bars and cross ditches) are more effective than the sediment filtering methods (slash dams and lopping and scattering of slash).

Gonsior and Gardner (1971) proposed design criteria for the improvement of logging roads in areas subject to slope failure. Road design has been dealt with in a previous report (EPA 1975).

The Tongass National Forest (1974) proposed as a means of reducing soil disturbance to, "Utilize winter snow conditions and frozen ground to minimize soil disturbance during timber harvest."

Hopkins (1957) made the following observations concerning the minimization of soil disturbance:

> Limb the logs before yarding. Be sure the loggers know the location of the skidtrails. Then, they can place the trees so that yarding crews can roll and skid the logs with a minimum amount of soil disturbance.
>
> Slash disposal is often considered soley as a method of reducing fire hazard. Don't overlook the opportunity, however, for using slash from tops and other debris to minimize or prevent erosion damage. Slash and litter properly placed in skidtrails will lessen soil movement and divert excess water out of trails; improperly placed, it is ineffective, wasteful of effort, and may even increase erosion. Place the material in good contact with the soil and the larger pieces at such angles that they will lead water out of the skidway at frequent intervals. Portable chippers, now in use on two of the southern California national forests, will chip slash and blow a mulch into old skidtrails and other bare and unstable areas. In general, the combination of good road location, well-placed waterbreaks, and slash placement in critical spots, will provide effective erosion protection.

The Federal Water Pollution Control Administration (1970) published Table 15 and recommended the following soil protection criteria.

> Limb all logs before yarding in order to minimize disturbance of soil and damage to reproduction and water quality.
>
> Avoid tractor yarding on all saturated areas and on all slopes steeper than 30 percent. On critical soils, limit crawler-tractor yarding to slopes of less than 15 percent.
>
> Minimize logging road construction on very steep slopes or fragile areas by using skyline or balloon yarding systems.
>
> Consider the use of helicopters, balloons, or modified cable systems for logging of areas that would have high conventional yarding costs or for fragile, sensitive areas.
>
> Take all possible care to avoid damage to the soils of forested slopes, and to the soil and water of natural meadows as well. Minimize this damage by operating the logging equipment only when soil moisture conditions are such that excessive damage will not result.
>
> Limit tractor-built firelines to areas where they will not involve problems in soil instability.

Table 15

RELATIVE EROSION HAZARD OF LOGGING AREAS IN RELATION TO SITE FACTORS

Site Factors	High Erosion Hazard	Moderate Erosion Hazard	Low Erosion Hazard
Parent rock	Acid Igneous Granite, diorite, volcanic ash, pumice, some schists	Sedimentary and Metamorphic Sandstone, schist, shale, slate, conglomerates, chert	Basic Igneous (Lava rocks) Basalt, andesite, serpentine
Soil	Light textured,[a] with little or no clay	Medium textured, with considerable clay	Heavy textured, largely clay and adobe
Mantle stability	Unstable mantles (cutbank stability Class V)	Mantles of questionable stability (cutbank stability Class IV)	Stable mantles (Classes I, II and III
Slope	Steep (over 50%)	Moderate (20-50%)	Gentle (0-20%)
Precipitation	Heavy winter rains or intense summer storms	Mainly snow with some rain	Heavy snow or light rain
Vegetation and other organic matter on and in the soil	None to very little	Moderate amounts	Large amounts

---

[a] Soil texture refers to the size and distribution of the mineral particles in the soil, the range extending from sand (light texture) to clay (heavy texture).

Silvicultural and Logging Systems Selection

The harvest or cutting method used has historically been based on the silvics of the tree species present, the profitability of the system used to extract the wood products, and the type of logging equipment available in the region. However, the silvicultural and logging systems (and support facilities) directly effect water quality. By recognizing this relationship, the water pollution potential of an area to be logged can be reduced through the selection and layout of the silvicultural and logging systems.

SELECTION

Summary

To reduce the effects of timber harvesting on water quality, a few general recommendations concerning selection should be followed:

1. Know the classes of stream within the cutting areas and the degree of protection needed (see the Washington and Oregon Forest Practices Acts 1974).
2. As a general rule, silvicultural systems rank in the following order regarding potential impact on water quality (most impactive first).
    a. clearcutting
    b. seed tree
    c. shelterwood
    d. selection

   (see Chapters 3 and 4)

3. Choose the type and size of logging equipment that will minimize soil disturbance. Logging systems which have a much greater range of potential impact than silvicultural systems, generally rank in the following order (most impactive first):

    a. tractor
    b. high lead
    c. skyline
    d. running skyline
    e. balloon
    f. helicopter

   (For additional information, refer to Chapters 3 and 4).

Discussion

Chapters 3 and 4 explain the various silvicultural systems including advantages and disadvantages from a water quality standpoint and this information will not be repeated here. A few points, however, will be emphasized.

Rothwell (1971) has stated that:

> "If clearcutting is employed, careful consideration should be given in the logging plan to size and distribution, both areal and temporal, of the cutting blocks. Generally speaking, increasing the size of clearcut blocks and shortening the cutting cycle will increase the potential for watershed damage.
>
> Considering a watershed as a whole, large clearcuts and a short cutting cycle concentrate the disturbance in area and time and increase the impact on watershed values. Furthermore, large cut blocks may create habitats that are difficult to revegetate, thereby extending the recovery period.
>
> Small cut blocks and longer cutting cycles may result in the same total amount of disturbance, but distribution in time and area reduces impact. In addition, residual vegetation maintains a forest environment and reduces and slows runoff, erosion, and the amount of sediment entering streams."

Harvesting with small cut blocks requires careful examination as total disturbance from roads and skid trails may increase the access network and offset mentioned advantages.

The inherent characteristics of the selection system make it the most desirable of the four silvicultural systems with regard to maintaining high water quality when skillfully applied. The biggest drawback from a water quality standpoint is the frequent return to the forest for periodic or even annual cutting, resulting in small disturbances occurring with greater frequency than with other silvicultural systems. Other drawbacks, especially on westside areas (with the exception of some high elevation fir--mountain hemlock types) and many eastside areas include:

- light requirements of some species e.g., Douglas-fir
- control of disease e.g., mistletoe
- terrain, species, tree damage, stand age

The selection of the logging system probably has more impact on water quality than any other single factor. This is due to (1) the road density requirements, which are largely set by the logging method and (2) the surface disturbance resulting from the various methods of transporting logs to the landing.

Lysons and Twito (1973) have enumerated some environmental and silvicultural criteria for determining the type of logging method to be chosen:

Environmental and silvicultural criteria

- Minimum landing area
- Minimum access road density
    - capability to yard extended distances
    - capability for uphill and downhill yarding
- Minimum soil and water disturbance, including soil compaction
- Minimum impact of fish, wildlife and range habitat
- Suitability for partial cuts and clearcuts
    - minimum damage to residual stand
- Suitability for harvesting irregular-shaped settings
- Suitability for clean yarding
- Minimum energy consumptions and air pollution

Economic criteria

- Minimum yarding cost
    - maximum production per man-day
    - maximum production per invested capital
    - minimum maintenance
- Minimum sensitivity to yield per acre
    - minimum move-in cost
    - minimum set-up cost
- Maximum return on stumpage
- Minimum invested capital
- Maximum reliability

Physical criteria

- Minimum sensitivity to ground profile
- Compatibility with the timber size
- Minimum sensitivity to atmospheric conditions
- Compatibility with health and safety codes
- Compatibility with road restrictions

Helicopter and balloon logging disturb the watershed the least, however, they are costly, more subject to climatic variables and present some residue management and regeneration problems. They do offer advantages in limited access or highly sensitive areas that might not otherwise be subject to logging. One of the most advantageous logging systems available is the running skyline. Its potential for use appears to be much more extensive than helicopter or balloon logging (Burke 1975).

LAYOUT

Summary

Emphasis must be placed on avoiding or minimizing disturbances on critical or sensitive areas. Proper timber management planning, however, should also include the identification and utilization of the most stable areas for locating logging facilities (e.g., landing) and systems (e.g., skidtrails).

In most northwest subregions, the greatest potential for reducing stream sedimentation related to silvicultural activities is in the minimization of logging road and skidtrail densities. Much of the literature concerning the Idaho Batholith, for instance, indicates that erosion and sedimentation are heavily influenced by the extent of the area distrubed by roads (Megahan and Kidd 1972 a and b).

Because of this relationship between density of logging roads and sedimentation, one method offers significant advantages for water quality protection. This is simply the reiterative layout on a topographic map of alternative road systems with the concomitant harvest and logging systems. This analysis allows the selection of a combination that minimizes soil exposure due to cut/fill and road surfaces. Such road/logging system selection should consider the following.

- minimizing total road density and soil disturbance
- avoiding critical or sensitive areas
- taking advantage of stable areas
- long term harvesting plans for areas allocated to intensive commercial timber use
- minimizing cut/fill surface area and ensuring that cut/fill slopes are less than maximum limits set for each soil type.

In addition the following recommendations concerning the layout of the silvicultural/logging systems and required support facilities (e.g. landings) will reduce the adverse water quality impacts:

1. Design cutting areas and use logging systems that avoid yarding across streams and minimize disturbance to stream bed and banks.
2. Use buffer strips of vegetation along streams to intercept sediments and organic material, maintain normal water temperatures and protect the stream from residue burning and disturbance due to the operation of logging equipment.
3. Avoid logging of steep unstable slopes which have landslide potential. Guidelines for identifying such areas are available for coastal Alaska (Swanston 1969), Oregon (Burroughs et al 1974), and the Intermountain Subregion (Bailey 1972).
4. Develop general drainage plans jointly with all owners in the vicinity of the operations.
5. Design with a minimum of roads.
6. Locate landings away from stream courses in well drained areas.
7. Avoid falling trees into or across streams. Remove logging debris from stream channels (see SAF 1959).

8. Restrict cable logging to uphill yarding. Depending on soil conditions, tractor or wheel skidding should not be used on steep slopes and during or immediately after heavy rains or snow melt periods.
9. Revegetate the area as soon as possible after logging. Stabilize roads, skid trails and landings.
10. Periodically inspect drainage previously established through proper construction of skid trails, landings, spur roads and fire lines and maintain to avoid future site degradation (SAF 1959).
11. Locate skid trails in tractor logging where they can be drained and construct with discontinuous grades (SAF 1959).
12. Initiate and complete post-harvest operations as soon as possible after logging.
13. Maintain good supervision of the personnel responsible for the operations.

Discussion

Burke (1975) has stated that, "Improperly located and constructed timber access roads and landings cause the greatest adverse environmental impact of all activities related to timber harvesting. It behooves the logging engineer to consider all alternatives, both in location and road standards, that:

1. Reduce amount of timber access road,
2. Reduce depths of cut and fill,
3. Eliminate necessity for steep, unnatural cut and fill slopes,
4. Eliminate necessity for steep road grades,
5. Reduce volumes of required excavation and embankment,
6. Eliminate indiscriminate sidecasting of excavated materials on slopes, and
7. Reduce amount of right-of-way clearing required for road or landing."

The FWPCA (1970) proposed criteria for facilities location and Hopkins (1957) stated the following as a guideline for locating landings:

> Locate landings in natural, level openings on firm dry ground whenever possible. In moderate terrain this is easily attained; in steep country, careful designation of landing sites is necessary to minimize watershed damage. Often you can make landings by widening the haul roads at some distance from water courses. Cribbing built with cull or unmerchantable logs and chunks on the downhill side will support a landing fill and thus minimize excavation.

Certain models or procedures have been developed for locating timber management facilities. Most of these "models" are based on economic feasibility, but could have programs for minimizing water quality degradation incorporated.

Such models concern facilities establishment (Gibson and Rodenberg 1974); helicopter refueling (Gibson 1974); helicopter landings (Egging and Gibson 1974); running skyline design (Parson, Studier and Lysons 1971); activity scheduling (Carson and Burke 1972); mobile crane yarding (Burke 1972); and access road alternatives (Burke 1974).

Since compacted soil areas are most often the critical sources of erosion after logging, judicious location and design of skidroads and trails is essential in order to decrease erosion potential. Dunford and Weitzman (1955) suggest the following as general guidelines:

1. Do not yard logs along stream channels. Locate landings so that logs are dragged away from streams rather than through or across them.
2. Keep skidtrails well drained by diverting the water into areas where the sediment can filter out. It is especially important that water bars and diversion ditches be installed after logging. Frequent inspection is needed in rainy periods to assure that the drainage checks are controlling surface flow.

3. Do not use tractors on steep slopes or wet ground. Tractor operations should be limited to less rugged terrain and to the dry seasons of the year. As a rough guide, 30 percent slopes are considered a desirable maximum for tractor operation on many types of soil. Soils are considered too wet when they contain water that can be squeezed out by hand.

4. Adapt logging equipment to logging conditions. On many Forest Service timber sales, high lead cable logging is specified on steep slopes.

Treatment of bare and compacted soil areas is essential. Since the greatest deterrent to erosion is cover, the manager's first job after disturbance should be to reestablish, as quickly as possible, a protective covering of vegetation and litter. In areas of compaction or exposed subsoil, natural revegetation may occur so slowly that seeding, fertilizing and mulching are necessary.

After logging has been completed certain management activities are usually required to complete the project and minimize long-term site disturbance. These include residue management, site preparation, regeneration, and stabilization (e.g., putting some of the roads and landings "to bed"). These have been discussed adequately in Chapters 3 and 4, and in a previous report (EPA 1975), and very little will be added here. An important overall consideration is the initiation and completion of these operations as soon as possible after logging, to minimize the period of high impact.

One important option involves the use of burning for residue disposal and site preparation. The Western Forestry and Conservation Association (1972) included the following, concerning prescribed burning, as to information needed on this subject:

1. Predictive models to enable the manager to select a burning schedule for a given set of conditions, topography, and other relevant factors, that will result in the minimum environmental impact.

2. A knowledge of the conditions under which natural accumulations of fuel occur, the rate of accumulation, and how the organic material can be reduced without burning.

3. Decision models that will assist the manager in evaluating the consequences of his selection from alternatives open to him, including the calculation of the probabilities of fire escape as part of the models.

4. More intensive studies to determine the effects of fire on forest ecosystems over time, and the effects of non-burning as well.

The USDA Forest Service (1975) has recently published guidelines for forest residue management for the Pacific Northwest which have applicability to water quality.

Mechanical methods of site preparation during the last ten years have included: scarification, stripping, and terracing (Packer 1971a). These have been discussed in Chapters 3 and 4.

One notable accelerated reforestation program is being practiced by the Weyerhaeuser Company. While seeding and other regeneration methods are used, the program also involves soil surveys, winter planting, a system of seed selection from similar sites and planning coordination between harvesting, nursery planting and reforestation. Most importantly, containerized seedlings are used on certain sites. Reforestation is generally accomplished within one year.

Log landings are an important source of sediment and require post-operation stabilization. The following procedures may be used;

Landing fill, like road fill, is an accumulation of unstable, loose soil highly susceptible to erosion. Cribbing, using cull logs or seeding and mulching can impart a degree of stability to the fill (California Water Resources Board).

Upon abandonment, 'erosion-proof' all landings by adequately ditching or mulching with forest litter, as needed. Establish an herbaceous cover on those areas that will be used again in repeated cutting cycles and restock to coniferous species those landings, located in clearcut areas, that will not be reused for a long time, if ever (FWPCA 1970).

Oregon State Forest Practices Rules state: "Leave or place debris and reestablish drainage on landings after use to guard against future soil movement."

NOTE

In addition to the following reference bibliography an annotated bibliography has been prepared. It is available upon request to U.S. Environmental Protection Agency, Region X, 1200 Sixth Avenue, Nonpoint Source Section, Seattle, Washington 98101.

The annotated bibliography is 103 pages long and contains a capsule write-up of many pertinent references. The coverage listed alphabetically by author usually ranges from one or two paragraphs to a full page. It is printed on standard white 8 1/2" x 11" paper.

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